FINAL REPORT

on

CAUSES OF CLEAVAGE FRACTURE IN SHIP PLATE: HATCH CORNER TESTS

by

E. PAUL DeGARMO, J. L. MERIAM AND M. P. O'BRIEN
UNIVERSITY OF CALIFORNIA
Under Navy Contract NObs-31222

COMMITTEE ON SHIP CONSTRUCTION
DIVISION OF ENGINEERING & INDUSTRIAL RESEARCH
NATIONAL RESEARCH COUNCIL

Advisory to

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Serial No. SSC-5

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October 23, 1946

NATIONAL RESEARCH COUNCIL
2101 Constitution Avenue
Washington, D. C.

October 23, 1946

Chief, Bureau of Ships
Navy Department
Washington 25, D. C.

Dear Sir:

Attached is Report Serial No. SSC-5, entitled "Causes of Cleavage Fracture in Ship Plate: Hatch Corner Tests". This report has been submitted by the contractor as the final report on the work done on Research Project SR-92 under Contract NObs-31222 between the Bureau of Ships, Navy Department and the University of California.

The report has been reviewed and acceptance recommended by representatives of the Committee on Ship Construction, Division of Engineering and Industrial Research, NRC, in accordance with the terms of the contract between the Bureau of Ships, Navy Department and the National Academy of Sciences.

Very truly yours,

Frederick M Feiker
Frederick M. Feiker
Chairman, Division of Engineering
and Industrial Research

Enclosure

PREFACE

The Navy Department through the Bureau of Ships is distributing this report to those agencies and individuals that were actively associated with this research program. This report represents a part of the research work contracted for under the section of the Navy's directive "to investigate the design and construction of welded steel merchant vessels".

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FINAL REPORT

U.S. Navy Research Project NObs-31222

CAUSES OF CLEAVAGE FRACTURE IN SHIP PLATE

Hatch Corner Tests

March 1, 1946 to August 31, 1946

From:
University of California
Department of Engineering
M.P. O'Brien, Technical Representative

Report prepared by:

E. Paul DeGarmo
J. L. Meriam

ABSTRACT

This report deals with the testing of seven large welded steel specimens similar in design to a square hatch corner of a ship. These were the last seven in a series of 26 such specimens which were tested to determine the performance of seven types of steel when built into a welded structure which had severe restraint to plastic flow due to a designed discontinuity. One of the last seven specimens was constructed of a 3-1/3 per cent nickel alloy steel and two from a low carbon steel having 0.82 per cent manganese. The others were made of three grades of plain carbon ship quality steel. Preheating at 400° F was used on three of the specimens.

The effect of preheating was very beneficial. The specimen constructed from nickel steel absorbed rather little energy before failure. This was attributed to the high yield strength of this material which prevented plastic flow of the plate before failure of the welded joints.

Conclusions based upon all of the tests on hatch corner type specimens are included along with recommendations for further work.

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INTRODUCTION

Starting November 1, 1944, a program of research was undertaken by the University of California under a contract with the NDRC having as its title "Cleavage Fracture of Ship Plate as Influenced by Design and Metallurgical Factors (NS-336)." Work under this project continued up to August 31, 1945, and was divided into two parts as follows:

A. A determination of the influence of metallurgical factors and temperature on the cleavage fracture of ship plate containing internal notches.

B. The determination of the effect of variation of material and temperature on the tendency for cleavage fracture of welded structural specimens containing a discontinuity, such as hatch corners.

Part B of this project involved the design and testing of full scale ship sections in order to:

a. Obtain a specimen approximating an actual section of a ship, wherein restraint to plastic flow is provided by the inherent geometry of the structure rather than by artificially induced notches.

b. Correlate the effects of temperature, steel, and stress relief on these specimens with results obtained on flat plate tests by other investigators.

Since September 1, 1945, this work has been continued by the University of California under a contract with the United States Navy, Contract NObs-31222.

In previous reports,[1,2] published by the Office of Scientific Research and Development, accounts were given of the development of a hatch corner type specimen containing a corner which had considerable restraint to plastic flow, and of the testing of thirteen of these specimens. A previous Progress Report of work done under U. S. Navy Contract NObs-31222[3] gave the results of tests on six additional specimens and some investigations into the effects of preheating.

This report covers the testing of seven additional full scale hatch corner type specimens which concluded the work done under the existing contract. This report makes use of the data given in the three reports mentioned above, so that conclusions may be drawn based upon all the work done to date on the hatch corner type specimens.

[1,2] See Bibliography

[3] See Bibliography

PROCEDURE

The design of the full scale hatch corner type specimen is shown in Fig. 1. Details of the welding procedure may be found in previous reports.[2,3] The analyses and strength properties of the seven steels which were used are given in Tables I and II.

The specimens which were tested are listed in Tables III and IV. This report is concerned particularly with specimens 20 to 26, inclusive. In making specimens 20, 21, and 23, preheat was used for all welds within two feet of the corner of the hatch. Heating torches were used to raise the temperature of the plates within three inches of the welds to 400° F. The temperature was not allowed to fall below this value until welding was completed. In making specimen 22 the preheat temperature was only 100° F. This amount of preheating was used only as a precaution to avoid cracking since a nickel alloy steel and 25-20 electrode were involved.

It was necessary to conduct two tests on specimen 21. On the first test failure of the aft end connection occurred when the nominal stress had reached 33,000 psi. At this point small cracks had appeared in the welds at the corner of the hatch. The specimen was removed from the machine and a new end tab attached. It was then retested to failure.

Strain gages were attached to the specimens at the locations shown in the small drawings at the bottoms of Tables III and IV, as had been done in previous tests. Readings of these gages were taken at loads of 0; 100,000; 200,000; 300,000; 600,000; 1,000,000; and 1,200,000 pounds. Beyond 1,200,000 pounds the readings of four gages were followed continuously up to failure, or until the gages became inoperative.

Over-all energy absorption was determined by taking pin-to-pin strain measurements, using the method discussed in previous reports.[2,3]

RESULTS

The results of the tests of twenty-six specimens are tabulated in Tables III and IV. It is felt that in order to interpret the energy absorption values shown in these tables only the values corresponding to failure of the longitudinal to hatch end beam joint should be considered. For specimens where cleavage failure occurred this also corresponds to failure of the deck. However, where shear fractures occurred if this method of interpretation is not used the "at failure" energy values become meaningless since they depend upon how far the tear was caused to progress across the deck before stopping the test. This distance was not the same in any two cases of shear fracture since in those tests which were conducted at low temperatures the specimen was enclosed in a canvas bag and could not be seen until the longitudinal girder joint had failed and the test was stopped.

Photographs of the failures in specimens 20 to 26 are shown in Figs. 2 to 41, inclusive. The load-strain curves for these specimens are shown in Fig. 42.

Referring to specimens 20 through 24, the beneficial effects of 400° F preheat are again apparent. Specimen 20 was essentially the same as specimen 8 but reached over 5,000 psi higher maximum stress. The energy absorption of this specimen was very outstanding, being about 23 per cent greater than that for any other specimen. Similarly in the case of specimen 21 as compared with specimen 4, about 7,000 psi greater stress was withstood when preheat was used. Again in the case of specimens 23 and 24 the use of preheat resulted in about 4,000 psi greater maximum stress even though the non-preheat specimen was a shear fracture. It should be noted that in the cases of steels C, B, and D, where preheat and non-preheat specimens were tested at the same temperatures, the increases due to preheat are from 18 to 36 per cent.

Preheating also appears to produce much greater uniformity of breaking stresses for specimens made of the various plain carbon steels. For specimens made of steels B, C, D, and H, with type E-6020 electrode without preheat, the maximum stresses varied from 23,200 psi to 31,200 psi, a range of 8,000 psi. For specimens made from these same steels with 400° preheat the variation in maximum stresses was only from 32,400 psi to 35,400 psi, a range of 3,000 psi.

It will be noted that in the case of specimen 21 the maximum stress reached during the first test was slightly higher than for the second test where failure occurred. The exact cause for this is not known but it may be due to strain age embrittlement since the retest was about two weeks after the first one. The load strain curve, shown in Fig. 42, indicates that this specimen was very nearly at its maximum possible load when the failure of the end tab occurred.

While the nominal breaking stress of specimen 22, made with "N" steel, is considerably greater than was obtained with the other steels, the energy absorption was much less than for several of the specimens made with the plain carbon steels. This situation is not surprising when one considers that the yield strength of this "N" steel was around 48,000 psi and that failure of the specimen was brought about by failure of the welded joints. The yield strength of the plate was so high that the over-all stress in the specimen reached a high enough value to cause failure of the weld joints before the plate was subjected to a sufficiently high stress to bring about much plastic flow. Thus in this case the energy absorbed was the result of a rather high load and very little elongation. This can be seen in Fig. 42 which shows the load-strain curve for this specimen. The performance of this specimen indicates that if it is desirable to have high energy absorption in a welded structure, the use of alloy steel having rather high yield strength and excellent impact properties is of little use unless the performance of the welds also is improved greatly.

A further indication of the effectiveness of preheating is obtained by computing the ratio $\frac{\text{nominal breaking stress of the hatch corner specimen}}{\text{yield point stress of the material}}$ for specimens made with and without preheat. Some of these are as follows:

Steel C, no preheat, tested at 68° F, cleavage fracture; ratio = 0.68
Steel C, preheat, tested at 70° F, cleavage fracture; ratio = 0.93
Steel N, no preheat*, tested at 35° F, shear fracture; ratio = 0.86
Steel H, no preheat, tested at 72° F, shear fracture; ratio = 0.69
Steel H, preheat, tested at 31° F, cleavage fracture; ratio = 0.82

As may be seen in Fig. 28 the cleavage fracture in specimen 23 extended through the 3 in. x 3 in. bar which was attached to the outboard edge of the specimen to permit the attachment of transverse restraining beams.[2,3] This bar had also fractured in specimen 2. However, in the case of specimen 23 this fracture was unique in that the crack went outboard in the deck plate to the outer edge and then inboard through the 3 in. x 3 in. bar.

The deck and doubler plates of specimen 24 were slightly laminated but it was not felt that this affected the test results.

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* 25-20 electrode used.

Fig. 43 shows the energy temperature relationship based upon the energy values corresponding to the failure of the longitudinal joint for specimens 10, 14, 25, and 26. This curve indicates that the transition temperature for steel "C" when built into the hatch corner type specimen is about 85° higher than when determined by Keyhole Charpy tests. The fracture obtained on specimen 26, as shown in Fig. 41, is of particular interest since it started in cleavage, changed to shear, then back to cleavage, later going into shear again and then back into cleavage with a small amount of shear at the fracture edges. Although the end of the fracture was predominantly cleavage it did not progress entirely across the specimen but stopped about 12 inches from the outboard edge. At the point where it stopped there was considerable local plastic flow.

CONCLUSIONS

These conclusions are based upon all of the work done on hatch corner type specimens under OSRD Contract OEMsr-1418 and U. S. Navy Contract NObs-31222.

1. Fractures such as occur in welded ships can be reproduced, both as to fracture type and reduction in thickness, in laboratory type tests of full scale hatch corner type specimens.

2. The nominal breaking stress over the load carrying area of the hatch corner type specimens was as low as 39 per cent of the nominal ultimate strength of the material as determined by ordinary tensile tests.

3. The full scale models were not as strong in proportion as quarter scale models (24,000 vs. 36,100 psi nominal breaking stress.)

4. Heat treatment of a hatch corner type specimen for 8 hours at 1000° F after welding with type E-6020 electrode gives about a 25 per cent increase in strength. Such treatment does not, however, change the type of fracture and does not give as great an increase in strength as can be obtained by using preheat at 400° F during welding. The post heat treatment decreases the hardness of the weld and the heat affected zone and alters the microstructure but not as much as preheating at 400° F.

5. The use of 25-20 electrode in such a structure increases the breaking strength by about 15 per cent as compared to E-6020 electrode.

6. When these specimens failed with cleavage type fractures, the strengths at room temperatures were slightly greater than when tested at 32° F.

7. The only steel which produced a shear type fracture at 32° F when built into a hatch corner type specimen was steel "N" containing about 3-1/3 per cent nickel.

8. When fabricated with preheat at 400° F and tested at temperatures which produced a shear type fracture, steel "B" was outstanding for its ability to absorb energy.

9. It is possible to obtain good correlation between the transition temperatures of steels in the hatch corner type specimens and in "tear test" specimens.

10. The use of preheating at 400° F was the most effective procedure tried, both as to increasing strength and energy absorption, being more effective than post welding heat treatment at 1000° F for 8 hours or the use of 25-20 electrode. Maximum strength was increased from 18 to 36 per cent by this procedure. The performance of the welds was greatly improved. Preheating does not appear to influence the type of fracture.

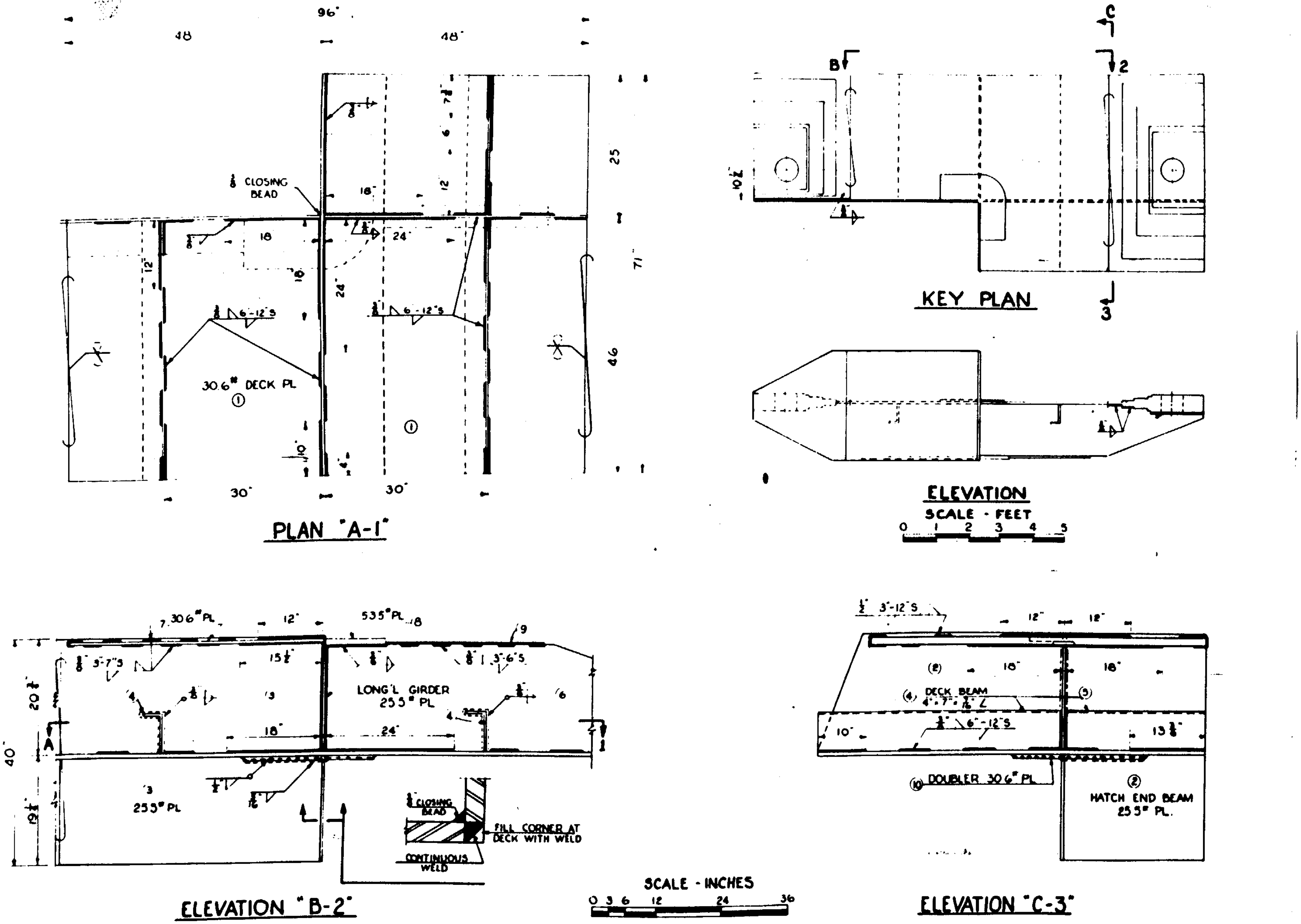
11. Keyhole Charpy tests over a range of temperatures appear to rate the various steels in the same order relative to transition temperature as do the full scale hatch corner tests. However, the transition temperatures for the steels when tested as hatch corner specimens are considerably higher than for Keyhole Charpy specimens. For steel "C" this temperature difference is 80° to 90° F.

12. Preheating at 400° F results in a softer weld and heat affected zone, gives a wider heat affected zone and produces a different microstructure than is found when welds are not preheated.

13. When a steel having a considerably higher yield point (such as steel "N") than low carbon steel is used in a rigid and complex structure, such as the hatch corner type specimen, the energy absorption may be less than that obtained from the use of low carbon steels fabricated with preheat. This is due to the fact that the welded joints fail before the stress has become high enough to produce any considerable amount of plastic flow in the steel. In order to obtain maximum benefit from the use of such higher strength steels in welded construction the performance of the welded joints must be improved.

14. The substitution of riveting for welding in the hatch corner type specimens did not give as high nominal breaking stress but did result in greater energy absorption than was obtained by welding without preheat. Although cleavage type fractures were obtained in the riveted specimens, in no case did they progress farther than the second rivet hole whereas in the welded specimens cleavage fracture always resulted in complete fracture of the deck and doubler plates.

15. The use of a highly notch resistant steel (steel "N") welded with 25-20 electrode did not result in as high energy absorption as was obtained with a low carbon, less notch resistant steel welded with type E-6020 electrode with preheat at 400°F.



REVISED DESIGN OF THE FULL SCALE HATCH CORNER MODEL

SCALE	AS SHOWN	APPROVED	
DR. BY	R SISSON	6/11/45	DWG R-301
TR. BY	RCG GP	7/23/47	PANEL

Fig. 31

BIBLIOGRAPHY

1 Progress Report on "Cleavage Fracture of Ship Plate as Influenced by Design and Metallurgical Factors (NS-336): Hatch Corner Specimen Tests", OSRD No. 5352, Serial No. M-512, July 21, 1945.

2 Final Report on "Cleavage Fracture of Ship Plate as Influenced by Design and Metallurgical Factors (NS-336): Hatch Corner Specimen Tests", OSRD No. 6387, Serial No. M-607, December 4, 1945.

3 Progress Report "Cleavage Fracture of Ship Plate as Influenced by Design and Metallurgical Factors: Hatch Corner Specimen Tests", U.S. Navy Research Project NObs-31222, September 1, 1945, to March 1, 1946. Serial No. SSC-1, dated July 24, 1946.

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The staff actively engaged in carrying out the work at the University of California included the following:

Harry L. Aldrich
Winona Bucklin
Earnest Bradford
Marvin G. Dailey
E. Paul DeGarmo
Raymond C. Grassi
John W. Harman
Margaret M. Jordan
James T. Lapsley, Jr.
Douglas M. MacMillan
James L. Meriam
Clarence Peters
Anne Shultis
Andrew Splinter
Richard Younie

RECOMMENDED FUTURE WORK

1. It appears desirable to test at 32° F a specimen constructed with steel "B" using preheat at 400° F. Because of the outstanding energy absorption of specimen 21, which failed with a shear type fracture, it would be interesting to know what the energy absorption would be at this lower temperature even though a cleavage type fracture would probably result.

2. Further investigations to determine the effects of preheating are most desirable. The results obtained on this project indicate that preheating produces greater benefits than are obtained from post welding heat treatment at 1000° F. In view of the many applications where post welding heat treatment is impracticable, or very costly, preheating should be fully investigated. Its effect upon energy absorption is of considerable importance in many naval applications.

3. Further studies should be made toward improving design details of various components of ship construction. The possibility of introducing more flexibility into welded joints and the prevention of severe restraint should receive careful consideration.

4. In order to determine the manner in which strength varies with size it would be desirable to construct and test a one-half scale hatch corner type specimen to bridge the gap in the data now on hand for one-quarter and full scale specimens.

5. It would be desirable to test a hatch corner type specimen the same as the existing specimen except having the longitudinal girder continuous instead of the hatch end beam.

TABLE I

Analysis of Steels

Steel	% C	% Mn.	% P	% S	% Si.	% Mo.	% Ni.	% Al
A*	0.23	0.47	0.011	0.042	0.02			
B*	0.15	0.76	0.010	0.030	0.04			
C*	0.24	0.49	0.015	0.033				
D	0.19	0.52	0.01[illegible]	0.02[illegible]	0.24			
E*	0.23	0.39	0.019	0.032	0.008			
H**	0.17	0.82	0.022	0.024	0.15	0.40		0.056
N*	0.13	0.49	0.018	0.027	0.22		3.34	

* Supplier's analysis

** Supplied by S. Epstein, Bethlehem Steel Company

TABLE II

Tensile and Hardness Properties

Steels for Hatch Corner Specimens

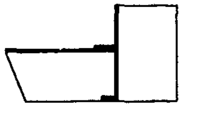
Plate No.	Direc.	Tensile Data (.505 Bars)					Hardness
		Yield (Psi)	Ultimate (Psi)	Break (Psi)	Elongation (% in 2")	Reduction in Area (%)	(Rockwell "B")
A-57	Long.	35,500	61,200	47,400	39.5	59.6	
	Trans.	38,100	60,400	48,800	36.2	56.3	
B-1	Long.	35,050	56,900	38,600	40.9	67.6	62
As rolled	Trans.	34,000	57,000	47,500	39.6	58.6	
B-6	Long.	36,900	59,500	43,400	39.3	64.0	64
Normalized	Trans.	36,500	57,200	43,500	38.5	63.0	
C-1	Long.	35,230	68,700	55,300	36.0	59.6	71
	Trans.	35,750	68,000	57,050	33.6	52.5	
D-2	Long.	37,800	63,700	46,900	37.2	62.8	68
	Trans.	40,600	63,600	48,600	36.6	59.6	
E-2	Long.	35,000	58,900	45,300	37.2	59.6	
	Trans.	35,300	58,200	46,200	35.6	58.0	
			Tensile Data (Full Thickness)				
A-57	Long.	35,100	61,400	47,900	49.2	58.7	
	Trans.	34,800	59,800	49,000	46.1	56.3	
B-1	Long.	31,000	56,500	43,700	53.2	66.6	
As rolled	Trans.	31,400	56,400	45,600	48.7	58.4	
B-6	Long.	32,200	56,900	41,100	52.0	64.0	
Normalized	Trans.	32,000	56,500	43,400	51.6	60.5	
C-1	Long.	37,500	66,500	53,600	45.5	56.5	
	Trans.	34,100	66,200	56,600	32.5	50.4	
D-2	Long.	35,900	61,300	45,800	47.1	62.3	
	Trans.	36,100	60,500	47,600	46.4	59.2	
E-2	Long.	31,400	57,200	44,500	49.1	59.1	
	Trans.	31,000	56,600	45,600	45.5	58.0	
H-1	Long.	37,000	63,700		43.0	68.6	70
	Trans.	33,900	63,200		41.5	59.0	
H-2	Long.	37,500	63,900		44.0	67.2	70
	Trans.	34,000	63,000		40.5	60.0	
N-3	Long.	58,000	82,000		38.0	61.5	85
	Trans.	52,750	83,300		32.5	54.0	

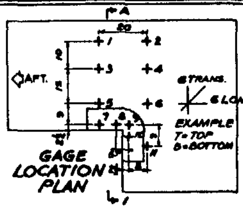
RESULTS, FULL SCALE HATCH CORNER TESTS

SPECIMEN NO.	KIND OF STEEL[4] AS ROLLED UNLESS NOTED	TEST TEMP °F	NOMINAL STRESS AT FAILURE[1] LB./IN²	LONGITUDINAL STRESS CONCENTRATION BASED ON 200,000 LB. LOAD[2]									STRAIN CONCENTRATIONS[3] FOR 200,000 LB. LOAD 1,200,000 LB. LOAD												
				GAGES									GAGES												
				5	6	7	8	9	10	17H	18	19H 19V	5L	6L	7L	8L	9L	12T 12B	13	14T 14B	15T 15B	16T 16B	17H 17V	18L	19H 19V
1	A	32	24,200	1.5	1.8	1.3	2.0	2.0	1.3	-1.7	1.9	6.2	1.4	1.8	1.4	1.8	2.0	2.5 2.4	2.7	0.9 0.5	3.0 —	1.6 —	-1.6 0.3	2.1	5.6 0.3
												2.1	1,000,000 LB. 1.8	2.3	1.3	0.9	1.9	1.7 4.0	14.4	-0.1 -0.1	2.1 —	3.2 —	-1.4 0.1	3.3	6.9 0.2
2	C	32	23,200	—	1.6	—	—	—	—	—	—	—	—	1.6	—	—	0.8	— —	—	— —	— —	— —	— —	—	— —
													1,250,000 LB. —	2.0	—	—	—	— —	—	— —	— —	— —	— —	—	— —
5	C	68	24,000	1.6	2.0	1.2	2.1	2.3	1.5	-1.9	2.6	10.4	1.6	2.0	1.3	2.0	2.2	4.5 3.0	3.0	0.9 0.3	4.7 3.9	3.2 1.5	-2.1 0.9	2.8	9.9 0.5
												3.4	2.0	2.0	1.1	2.0	2.9	2.0 4.4	11.9	-0.5 -0.3	2.3 6.5	— 2.5	-1.5 0.4	2.1	10.6 -8.2
10	C MUREX H.T.S.	32	23,600	1.5	2.0	1.7	2.5	2.1	1.6	-1.9	2.5	13.8	1.5	1.9	1.8	2.2	1.9	3.4 2.6	2.7	0.3 0.5	3.4 3.5	1.3 1.1	-2.3 1.8	2.7	13 0.3
												4.3	2.2	2.5	1.4	5.2 ←8	4.0 ONLY→	— 11.5	—	— 2.1	— 12.2	— 0.8	-2.9 -0.2	5.8	1.7 1.0
9	C STR. REL. AFT. WELD	72	MAX. STRESS 30,000 29400	1.5	1.8	1.7	2.4	2.4	1.8	-1.5	2.6	8.4	1.4	1.8	1.8	2.1	2.3	2.9 2.9	1.2	1.1 0.4	2.9 3.4	1.2 1.1	-1.9 1.7	2.8	7.9 0.2
												2.6	1.6	2.0	1.5	3.6	2.0	2.0 6.5	7.1	0 0.1	2.3 5.0	1.9 1.0	-1.6 0.8	2.2	14.3 0.1
13	C 25-20 ELECTR.	32	27,700	1.7	2.0	1.8	2.7	2.4	1.6	-1.7	2.7	7.1	1.6	2.0	1.7	2.3	2.2	3.5 1.5	—	1.0 1.0	3.5 2.8	1.6 0.5	-2.2 2.3	2.8	6.7 -1.3
												0.7	1.9	2.2	1.5	3.3	2.4	6.4 7.2		1.5 4.3	8.7 6.2	3.4 0.7	-3.1 3.7	5.0	5.3 -3.1
11	B	32	MAX. STRESS 25,700 25,600	1.6	—	1.6	2.2	2.3	1.2	-1.1	2.7	8.9	1.7	1.9	1.7	2.2	2.4	4.2 3.3	1.7	0.6 1.0	5.0 3.8	1.3 1.4	-1.6 1.3	3.1	9.6 -0.2
												2.4	2.1	2.0	1.3	5.8	2.2	8.5 12.6	2.9	-0.2 1.0	9.1 9.9	-2.4 0.2	-1.2 1.5	6.6	4.4 -1.9
8	B	66	MAX. STRESS 27,000 26,100	2.0	2.3	2.0	2.9	2.9	1.8	-2.7	3.0	18.9	2.0	2.2	2.0	2.6	2.6	4.5 3.8	3.6	0.2 1.0	5.3 4.3	1.3 1.3	-2.6 1.8	3.2	17.3 0
												5.5	2.2	2.0	1.4	7.4	4.2	6.7 17.9	19.8	-1.4 1.4	7.6 18.3	-2.0 -0.1	-2.2 1.3	7.5	1.5 -0.8
3	B NORMALIZED	32	MAX. STRESS 26,900 23,500	1.4	2.1	1.5	2.3	2.1	1.6	-0.8	2.5	5.1	1.4	2.1	1.5	2.1	2.1	2.6 2.5	1.8	0.6 —	— —	— —	-1.1 1.2	2.6	4.8 0.2
												1.7	1.7	2.4	1.5	4.0	2.3	3.1 7.4	10.0	0 —	— —	— —	-4.1 2.0	3.3	4.0 -0.7
4	D NORMALIZED	32	25,900	1.4	1.7	0.9	2.2	2.0	1.5	-0.8	1.9	—	1.4	1.7	1.0	2.0	1.9	2.6 —	1.7	0.4 0.2	3.0 —	1.6 0.7	-1.2 1.3	2.3	— -1.0
												—	1.8	2.4	1.1	3.4	2.4	4.8 —	6.4	0.2 -0.1	3.6 —	4.2 1.6	-1.4 1.1	3.4	— -1.9
7	D NORMALIZED	72																							
12	D NORMALIZED	72	MAX. STRESS 27,800	1.5	1.5	1.7	2.4	—	1.3	-1.4	3.5	14	1.5	1.6	1.6	2.2	—	3.0 2.8	1.6	0.9 0.5	3.3 3.3	1.5 0.6	-1.8 1.7	3.6	1.3 -0.4
												3.6	1.8	2.1	1.7	3.7	—	3.6 5.9	11.7	-0.8 -0.2	4.2 7.0	6.7 0.6	-2.4 0.5	4.7	12.4 -0.5
6	E	32	23,100	1.5	1.7	1.4	2.1	2.0	1.4	-1.1	1.8	5.9	1.4	1.7	1.5	1.9	2.0	2.6 2.4	2.5	0.2 0.3	2.9 2.8	1.6 1.1	-1.3 0.8	2.0	3.9 -1.0
												0.7	2.0	2.1	1.5	3.1	2.5	3.9 5.9	12.0	-0.2 0.1	3.9 6.9	2.7 3.5	-1.5 0.7	1.0	6.6 -1.3

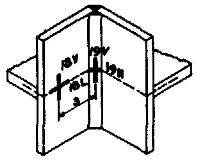
SPECIMEN NO.	TOTAL ENERGY ABSORBED PIN TO PIN IN. LB.		STRAIN RATIOS LONG./TRANS. 200,000 LB. LOAD 1,200,000 LB. LOAD									STRAINS AT OR NEAR FAILURE MICRO IN/IN				THICKNESS REDUCTION AT FRACTURE %						REMARKS
			GAGES									GAGES				DISTANCE FROM						
	AT MAX LOAD	AT FAIL.	5	6	7	8	9	10	11[5]	19H/19V	17H/17V	12B	15B	18L	19H	CORNER IN.	FRACTURE EDGE IN. 1/16	1/4	1/2	3/4	1	
1			-6.3	-3.7	-2.6	—	-4.7	6.7	-3.5	20.2	-4.8					20	2.4	1.5	0.7	—	—	CLEAVAGE FAILURE. STEEL A USED FOR DECK ONLY.
			-4.0	-2.5	-3.3	1,000,000 LB. 8.2	-5.5	3.4	-5.7	32.2	-11.9					32	3.2	2.1	0.8	—	—	
2			—	-2.8	—	—	0.9	—	-4.2	— —	— —					16	1.1	0.2	0	—	—	CLEAVAGE FAILURE. GAGE READINGS UNRELIABLE DUE TO DIFFICULTIES IN SWITCHING CIRCUITS.
			—	-4.3	—	1,250,000 LB. —	—	—	13.6	— —	— —					32	1.2	0.5	0	—	—	
5			-8.1	-4.2	-2.6	12.0	-11.0	4.7	-7.2	21.7	-2.3	3600	5000	—	7000+	19	1.9	1.0	0.3	0	0	CLEAVAGE FAILURE. SLIGHT AM'T OF SHEAR AT TOP & BOTTOM EDGES ALONG FRACTURE.
			-7.4	-75.4	-4.3	10.8	-17.1	—	79.4	-1.3	-3.5					34	2.3	0.9	0.1	0	0	
10			-7.6	-6.4	-4.7	7.4	—	7.2	1.3	4.8	-1.3	9200	8800	4400	13,800	19	1.5	0.9	0.4	0	0	CLEAVAGE FAILURE. SMALL CRACK IN DOUBLER OCCURED AT 400,000 LBS. PASSING DIRECTLY THROUGH GAGE #13.
	180,000	180,000	-4.0	-5.5	-4.2	10.1 ←8	-7.1 ONLY	-15.5 →	—	-1.7	1.3					34	2.0	1.3	0.5	0.1	0	
9			—	-3.7	-4.5	4.8	—	5.7	-3.7	3.6	-1.1	12,300+	15,200	9,200	14,300+	19	1.9	1.1	0.3	0.2	0.1	CLEAVAGE FAILURE. FILLET WELD BETWEEN TRANSVERSE COAMING AND DOUBLER FAILED PRIOR TO MAIN FAILURE.
			-7.3	-3.5	-3.6	12	-15	6.3	-18	30.0	-2.1					34	1.9	1.2	0.7	0.4	0.2	
13			-5.1	-3.7	-2.9	10.4	-7.2	1.1	-7.7	-5.2	-1.0	9400	8300	6,200	—	19	0.5	0.3	0.1	0	0	PULLING TAB FAILED AT 1,595,000 LB. TAB REPAIRED AND SPECIMEN RELOADED. CLEAVAGE FAILURE OCCURED AT HATCH CORNER.
	232,000	232,000	-4.1	-4.1	-2.8	6.0	-14.4	-10.6	-24.1	-1.7	-0.8					34	1.5	0.8	0.1	0	0	
11			—	—	—	4.2	—	2.0	10.8	-4.8	-1.2	13,500	7,900+	7,300	5,500	19	1.3	1.1	0.7	0.5	0.3	CLEAVAGE FAILURE.
	340,000	522,000	-4.0	—	-6.0	13.0	-7.4	-2.6	11.3	-2.4	-0.8					34	3.3	2.5	1.5	0.7	0.1	
8			-6.5	-4.3	-3.3	8.5	—	6.0	-6.4	—	-1.5	14,400+	13,200+	7,800	15,000+	NO MEASUREMENTS POSSIBLE. PART SHEAR, PART CLEAVAGE. SEE PHOTOGRAPHS						DECK FAILURE EXTENDED ABOUT 3" FROM CORNER IN SHEAR, THEN SUDDEN CLEAVAGE FAILURE OCCURED EXTENDING ABT. 18" FROM CORNER, ENDING IN SHEAR
			-3.0	-7.5	-2.4	6.5	-11.7	-0.6	5.8	-1.9	-1.7											
3			-10.2	-6.7	-5.6	4.6	—	3.1	—	2.3	-0.9					16	2.9	1.9	1.3	—	—	SUDDEN NOISE AT 1,600,000 LB. LOAD DROPPED & CLEAVAGE FAILURE OCCURED AT 1,400,000 LB. NO TRANSVERSE BARS USED. DECK LAMINATED.
			-3.0	-7.4	-3.0	—	-10.8	5.7	—	-5.7	-2.1					34	1.9	0.8	0.4	—	—	
4			-7.0	-4.8	-2.6	3.5	—	8.3	—	—	-0.9					19	1.2	0.7	0.5	0.3	0.2	CLEAVAGE FAILURE
			-4.6	-4.2	-2.2	14.0	-32.2	4.4	30.1	—	-1.3					34	2.5	0.7	0.5	0.4	0.3	
7																						TEST INVALID DUE TO WELDING DIFFICULTIES.
12			-5.7	-3.1	-4.8	7.5	—	0.9	-3.5	-2.9	-1.1	7,300	6,700	4000	10,700	SHEAR FAILURE						SHEAR FAILURE AT CORNER.
	514,000	1,196,000+	-3.4	-2.9	-4.0	9.4	—	1.8	-1.8	-2.3	-4.6	(AT	MAX.	LOAD)		SEE PHOTOGRAPHS						
6			—	-6.9	-5.4	9.0	-12.3	—	—	-5.8	-1.6	4400	5000	500	9400	19	0.3	0	0	0	0	CLEAVAGE FAILURE.
			-3.5	-5.6	-3.4	-6.1	—	—	24.0	-5.0	-2.2					34	1.6	0.8	0.1	0	0	

NOTES
1. BASED ON LOAD CARRYING SECTION OF DECK, DOUBLER, LONGITUDINAL COAMING BELOW DECK.
2. BASED ON AVERAGE OF LONGITUDINAL STRESSES FOR GAGES 1-2-3-4 TOP AND BOTTOM.
3. BASED ON AVERAGE OF LONGITUDINAL STRAINS FOR GAGES 1-2-3-4 TOP AND BOTTOM.
4. E-6010 & E-6020 ELECTRODE USED UNLESS NOTED.
5. READINGS QUESTIONABLE. GAGE #11 VERY CLOSE TO DOUBLER WELD.


LOAD CARRYING SECTION A-1



GAGE LOCATION PLAN



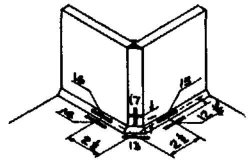


TABLE III

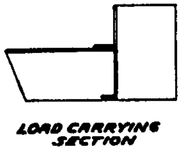
RESULTS, FULL SCALE HATCH CORNER TESTS

SPECIMEN NO.	KIND OF STEEL[4] AS ROLLED UNLESS NOTED	TEST TEMP. °F.	NOMINAL STRESS AT FAILURE[1] LB IN²	LONGITUDINAL STRESS CONCENTRATION BASED ON 200,000 LB. LOAD(2)									STRAIN CONCENTRATIONS(3) FOR 200,000 LB. LOAD 1,200,000 LB. LOAD												
				GAGES									GAGES												
				5	6	7	8	9	10	17	18	H 19 V	5L	6L	7L	8L	9L	12T 12B	13	14T 14B	15T 15B	16T 16B	17H 17V	18L	19H 19V
14	C	120	(AT MAX. LOAD) 25,600	2.0	2.1	1.5	2.4	2.2		-2.0	2.7	14	2.0	2.1	1.6	2.3	2.2	3.5 3.5		0.5 0.3	4.4 3.8	1.8 7.5	-2.3 1.4	2.9	13.9 -0.5
												3.6	2.2	2.7	1.3	2.9	1.3	3.5 7.0	15	-1.0 0.2	3.2 6.0	1.5 0.5	-2.5 0	3.3	15.0 1.2
15	C 400° PREHEAT	70	32,600			1.6	2.5	2.3	1.9	-1.5	2.7	16			1.6	2.1	2.2	3.2 2.8	1.6	0.7 0.4	3.4 3.4	1.6 1.0	-1.9 1.9	2.9	15 -0.7
												4.0			1.2	2.2	2.1	4.0 4.2	7.8	-0.5 1.2	5.1 6.5	3.7 1.4	-1.9 1.2	3.0	19 -1.6
16	C RIVETED	70	20,900	2.0	1.9	2.4	2.4	2.7			1.2		2.0	2.2	2.3	2.3	2.7							2.0	
													1.8	.9	.4	5.7	3.9							.4	
17	C	72	24,800	.3	1.2	.9	1.5	1.2	.7	-1.0	1.5	3.0	1.0	1.3	1.1	1.5	1.3	2.7 1.9	2.1	0.3 0.3	2.6 2.0	1.1 0.7	-1.2 0.8	1.7	9.8
												2.6	2.0	2.3	1.5	3.4	3.3	1.6 3.1		-.6 -.7	1.7 4.1	6.9	-1.8 0.7	2.4	0.3
18	C 400° PREHEAT	70	32,800																						
19	C RIVETED	70	(AT MAX. LOAD) 20,600																						
20	B 400° PREHEAT	AT END OF TEST 75	AT MAX. LOAD 32,400	1.6	1.7	1.4	2.3	2.1	1.5	1.1	2.3	8.4	1.5	1.8	1.5	2.2	2.1	2.7 2.9	1.6	0.5 0.5	3.1 3.2	1.5 0.9	1.6 -2.0	2.5	8.3 -0.5
												2.0	1.5	2.8	1.3	2.8	1.8	7.6 5.3	7.2	-0.2 0.8	7.8 6.4	5.5 1.0	0.3 -2.1	4.7	9.3 -2.3
21	D 400° PREHEAT	31	33,000 (1ST TEST)	1.5	1.4	1.3	2.3	2.2	1.9	-1.7	2.3	16.	1.5	1.5	1.3	2.1	2.2	2.9 2.9	.8	0.9 0.3	3.1 3.5	2.1 0.1	-2.0 1.5	2.6	15 -0.4
		33	(2ND TEST) 32,600 MAX. 31,000 FAILURE									4.3	1.3	2.3	1.1	2.8	2.1	4.2 3.4	2.7	0.8 0.4	4.6 4.0	5.4 0.3	-1.8 1.0	2.2	13 -0.7
22	N 25-20 ELECTRODE 100° PREHEAT	35	40,400	1.5	2.0	1.6	2.3	2.5	.7	.5	2.6	9.6	1.4	2.1	1.6	2.3	2.4	3.0	3.6	.5 .6	3.6 3.9	1.3	1.1 3.0	2.8	9.0 .1
												2.7	1.6	2.1	1.5	2.7	2.2	3.1	8.0	.1 .3	5.1 4.4	.3	-2.4	2.9	13.6 -.3
23	H 400° PREHEAT	31	35,400 MAX. 34,900	1.7	2.0		2.1	2.1			2.5	6.1	1.6	2.1		1.8	2.0	2.7 2.1	1.8	.9 -.4	3.2 3.2	.7 1.1	-1.6	2.7	5.9 -.3
												1.5	1.7	2.2		2.2	2.0	5.9 2.1	9.8	-.4 .7	7.5 3.6	1.9 1.5	-11.8	4.4	11.8 -2.3
24	H	72-75	31,200 MAX. 29,600	1.5	2.0	1.7	2.4	2.0	0.9	-1.5	2.2	19.	1.5	1.6	1.7	2.3	2.0	2.3 2.4	2.1	.3 .7	3.9 3.3	1.8 1.5	-2.0 2.1	2.4	18. -.5
												5.1	2.3	1.8	1.4	2.8	3.3	3.1 3.2	8.3	-.7 .3	10.8 4.3	.6 6.2	-1.6 8.9	4.6	23. -4.9
25	C	142	29,200 MAX. 26,700	1.7	2.0	1.3	1.5	2.1	1.0	.3	2.5	21	1.8	2.1	1.4	1.5	2.1	3.7 3.1	2.5	-.2 .8	3.7 3.7	2.5 .6	.3 -2.1	2.8	19.4 -1.6
												4.5	2.2	2.4	1.4	2.5	3.5	2.6 8.0	10.7	-.8 .3	3.7 8.1	.6	.2 -2.0	4.1	-2.0
26	C	100	27,400 MAX. 24,300	NO CONCENTRATION RATIOS POSSIBLE DUE TO FAULTY CONNECTIONS OF GAGES (4																					1.3

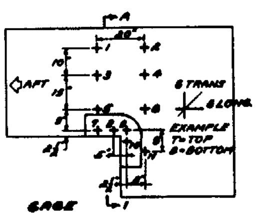
SPECIMEN NO.	TOTAL ENERGY ABSORBED PIN TO PIN IN.LB.		STRAIN RATIOS LONG./TRANS. 200,000 LB. LOAD 1,200,000 LB. LOAD									MAXIMUM STRAINS AT OR NEAR FAILURE MICRO IN/IN				THICKNESS REDUCTION AT FRACTURE %						REMARKS
			GAGES									GAGES				DISTANCE FROM CORNER IN.	FRACTURE EDGE IN.					
	AT MAX LOAD	AT FAIL.	5	6	7	8	9	10	11(5)	15H/19V	17H/17V	12B	15B	18L	19H		1/16	1/4	1/2	3/4	1	
14	289,000	484,000 AT FAILURE OF LONGITUDINAL GIRDER	-11.2	-5.5	-3.9	11	-6.8		-8.3	-29	-1.6	8,400	11,700	1,800	12,000+	SHEAR						SHEAR FAILURE AT CORNER.
			-3.5	-4.5	-3.0	-7.8	-3.7		12	12	69											
15	1,046,000				-3.1	3.0	-6.1	5.4	5.7	-21	-1.0	11,000+	12,000+	13,000+	20,000+	19	0.8	0.3	0	0	0	CLEAVAGE FAILURE AT CORNER. (SHEAR IN WELDS)
					-3.8	2.6	-17	17	-2.8	12	-1.7					34	1.8	0.1	0	0	0	
16	730,000		-4.4	-1.7	-13	-13	-3.1		2.5					1,000								CLEAVAGE FAILURE AT CORNER. VALUES SHOWN ARE FOR GAGES 3 OR MORE DIAMETERS FROM RIVET HOLE.
			-2.0	-5.9	-7.1	-9.8	-12.7		.3													
17			-6.9	-3.6	-2.6	2.1	-6.2	5.2	-4.6		-1.6	1,100	1,100	1,400	1,800	19	2.7	2.3	1.7	1.2	0.5	SUBJECTED TO REPEATED LOADING. CLEAVAGE FAILURE AT CORNER.
			-3.9	-3.3	-3.0		-14	-6.1			-2.6					34	1.4	1.4	1.3	1.0	0.5	SEE NOTE (6) AT BOTTOM OF TABLE.
18	1,358,000																					CLEAVAGE FAILURE AT CORNER. NO GAGE READINGS TAKEN.
19	① 412,000 SEE REMARKS	② 588,000																				CLEAVAGE FAILURE AT CORNER. NO GAGE READINGS TAKEN. FAILURE PROCEEDED HALFWAY THROUGH DOUBLER① & LATER CONTINUED TO SECOND RIVET HOLE.②
20	2,012,000	AT END OF TEST 2,758,000	17.5	-4.9	-3.0	6.7	-13	5.2	-8.3	-17	-.8	15,400	14,900	12,200+	9,600+	SHEAR						SHEAR FAILURE IN DECK, SHEAR & CLEAVAGE IN DOUBLER. UNUSUALLY LITTLE DISTORTION UP TO 1,200,000# LOAD. EXCELLENT WELD PERFORMANCE.
			-1.9	-2.2	-2.6	7.0	6.0	4.4	-4.0	-4.0	-.4											
21	952,000		-7.2	-3.0	-5.1	5.2	-12.7	5.4	-8.9	-39	-1.3	15,000	15,700	11,200	12,500+	NO FRACTURE IN DECK PLATE						CLEAVAGE FAILURE IN AFTER END TAB.
	390,000	920,000	-2.3	-4.3	-3.8	6.1	-33	3.0	-7.7	-18	-1.8											CLEAVAGE FAILURE OF DOUBLER. SMALL CRACKS IN DECK PLATE. NO GAGE READINGS TAKEN IN 2ND TEST.
22	372,000		-6.0	-3.1	-4.6	-4.8		.7			.4	6,800	9,300	5,700	12,100	SHEAR						SHEAR FAILURES IN DECK & DOUBLER.
			-5.7	-3.8	-2.8	-10		.8		-40												
23	1,570,000	1,622,000	-15	-2.9		3.4	-19		.1	-22		15,600	15,100	14,900	12,100+	19	0.8	0.5	0.3	0.1	0	CLEAVAGE FAILURE OF DECK, DOUBLER & 3"X3" RESTRAINING BAR WELDED TO OUTBOARD EDGE.
			-2.2	-2.9		4.3	-17		-4.6	-5.1						34	0.8	0.5	0.3	0.1	0	
24	918,000	1,210,000	-5.1	2.3	-4.2		-8.5	-4.2	-4.0	-39.	-1.0	10,900	5,500	5,000	11,000 AT 1,200,000# LOAD	SHEAR						SHEAR FAILURES IN DECK & DOUBLER. FAILURE OF LONGITUDINAL GIRDER. DECK & DOUBLER PLATES SLIGHTLY LAMINATED.
			-3.0	2.0	-3.0	-7.5	5.7	2.7		-4.6	-.2											
25	594,000	860,000 AT FAILURE OF LONGITUD. GIRDER	-2.3	-2.4	-2.2	-3.0	-3.4	7.0	-3.5	-12	-.4	9,400	9,300	4,000	8,700 AT 1,000,000# LOAD	SHEAR						SHEAR FAILURES IN DECK & DOUBLER. FAILURE OF LONGITUDINAL GIRDER.
			-3.1	-15	-2.4	-28		-1.8	-10		-.1											
26	942,000 ① SEE REMARKS	788,000 ②	-3.1	-2.7	-2.5	-5.3	-5.3	4.5	-5.0		-3.5		5000	1700	12,400 AT 1,000,000# LOAD	13	1.5	1.3	1.1	.9	.8	① FAILURE OF LONGITUDINAL GIRDER & 3" CLEAVAGE FRACTURE IN DECK & DOUBLER.
			-2.6	-2.8	-2.7	-3.5	-3.3	-2.7														② COMPLETION OF DECK & DOUBLER FRACTURES.

NOTES:

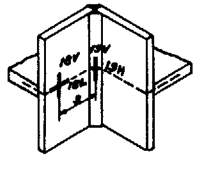
1. BASED ON LOAD CARRYING SECTION OF DECK, DOUBLER, LONGITUDINAL COAMING BELOW DECK. (ACTUAL PLATE THICKNESS)
2. BASED ON AVERAGE OF LONGITUDINAL STRESSES FOR GAGES 1-2-3-4 TOP & BOTTOM.
3. BASED ON AVERAGE OF LONGITUDINAL STRAINS FOR GAGES 1-2-3-4 TOP & BOTTOM.
4. E-6010 & E-6020 ELECTRODE USED UNLESS NOTED
5. READINGS QUESTIONABLE. GAGE #11 VERY CLOSE TO DOUBLER WELD.

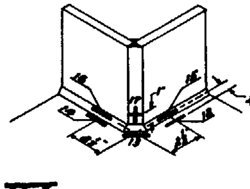


LOAD CARRYING SECTION A-1

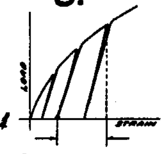


GAGE LOCATION PLAN





6.



STRAIN INCREMENT USED IN COMPUTATIONS

TABLE IV

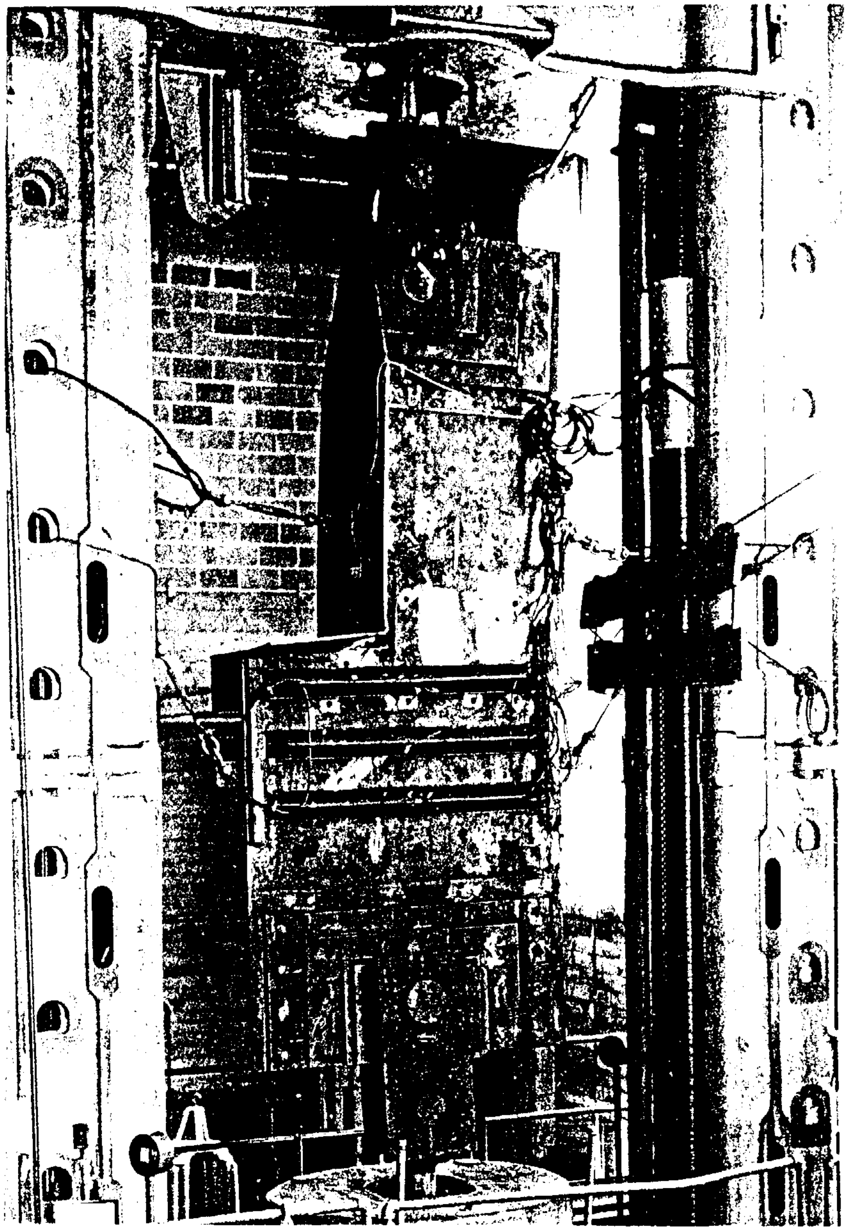


Fig. 2 Specimen 20: Overall view, above deck

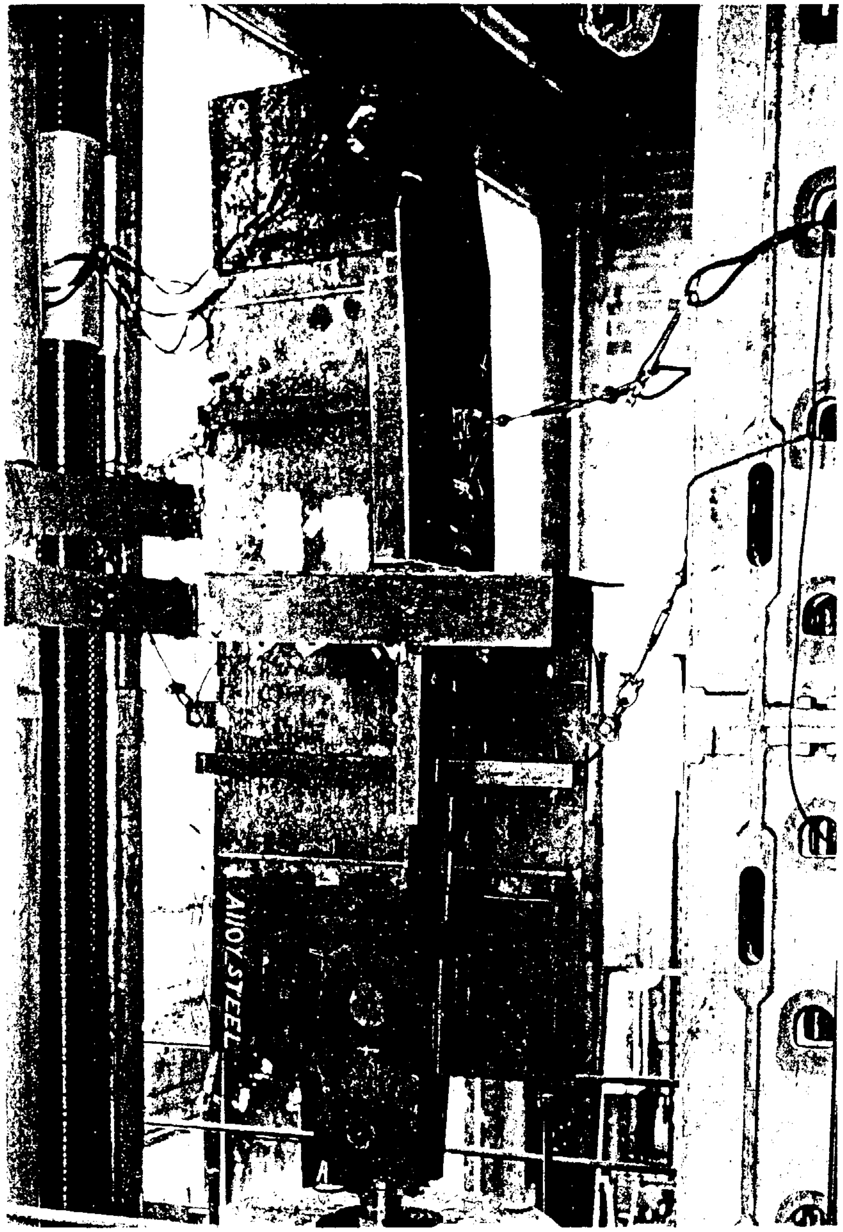


Fig. 3 Specimen 20: Overall view, below deck

Fig. 4 Specimen 20: View of fracture from above deck

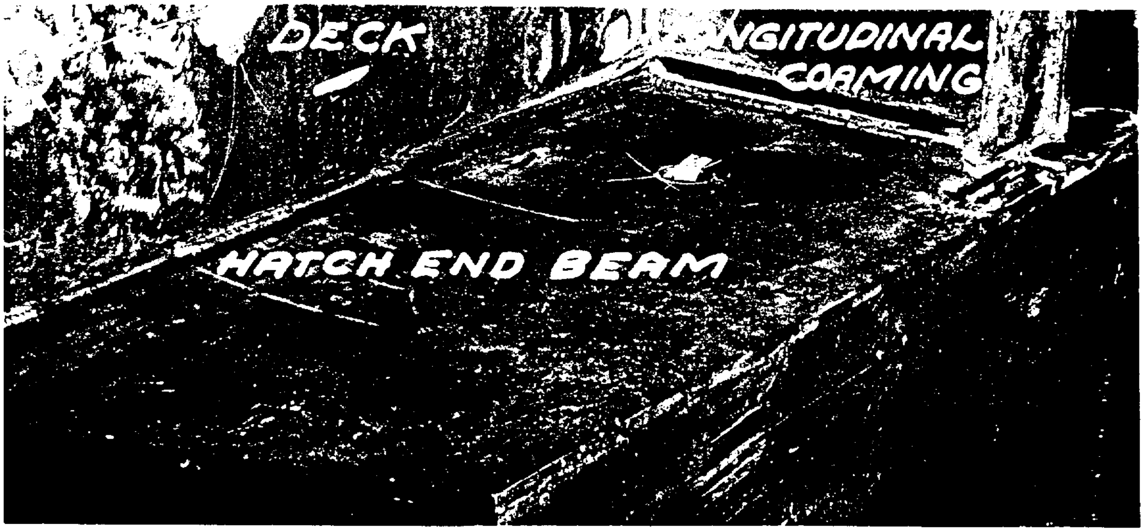


Fig. 5 Specimen 20: View of fractures from below deck, outboard, and aft of hatch end beam

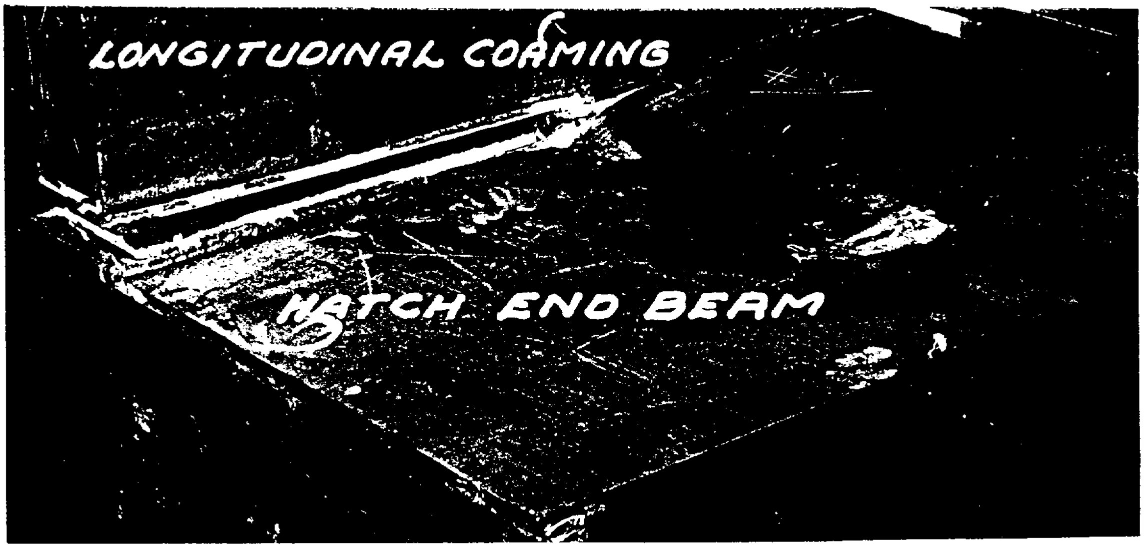


Fig. 6 Specimen 20: View of fracture in corner from inside of hatch

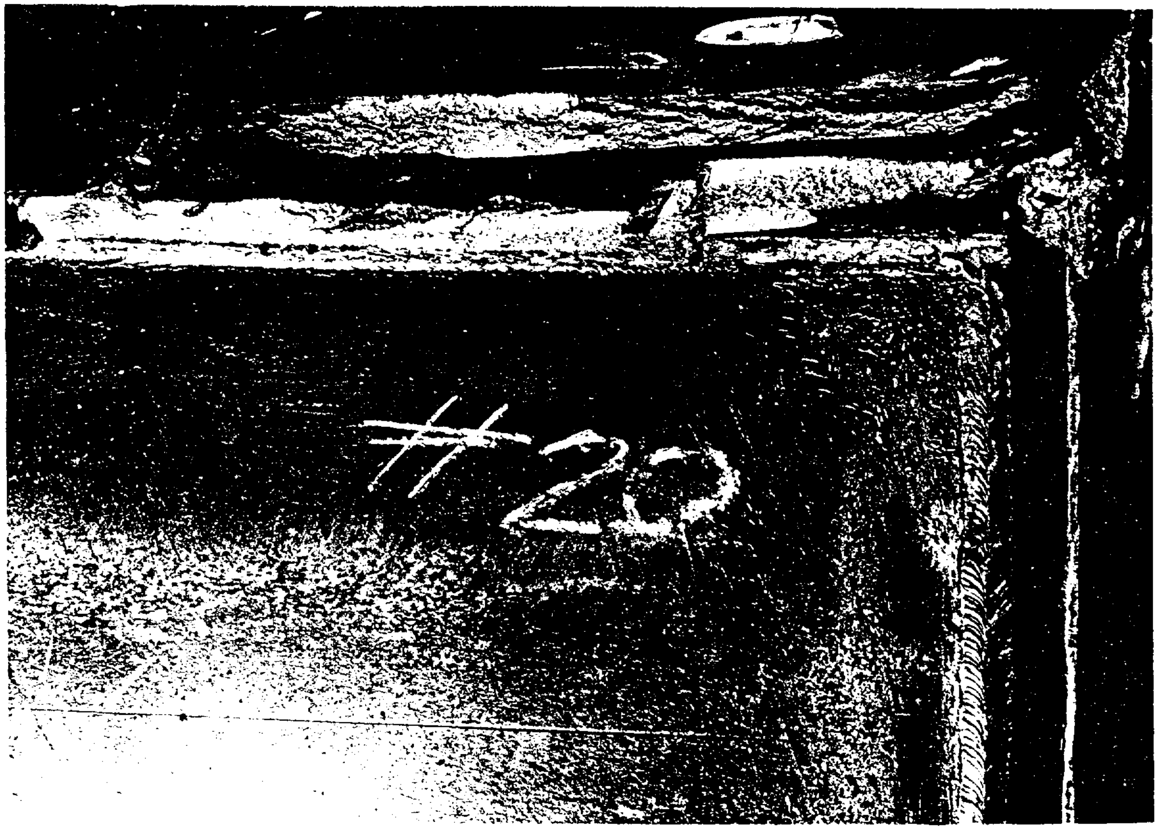


Fig. 7 Specimen 20: Deck and doubler fracture patterns, looking fwd.

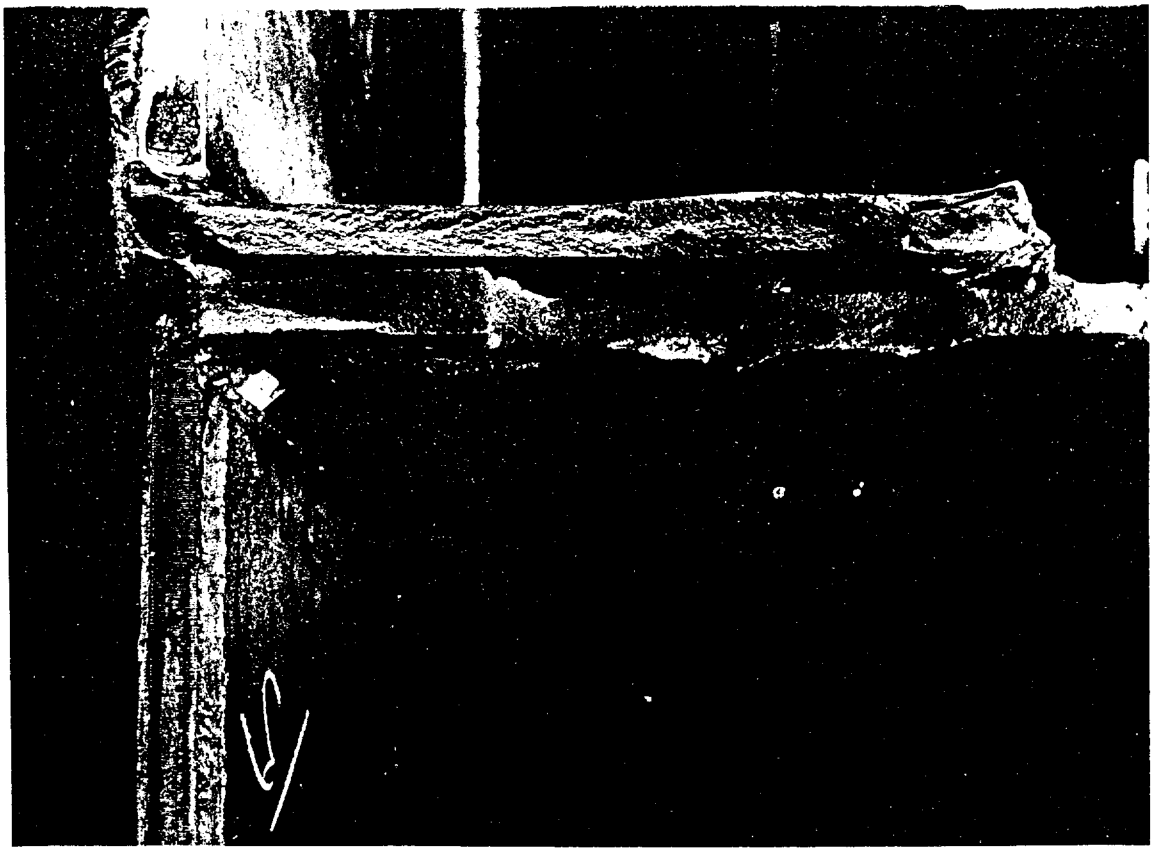


Fig. 8 Specimen 20: Deck and doubler fracture patterns, looking aft

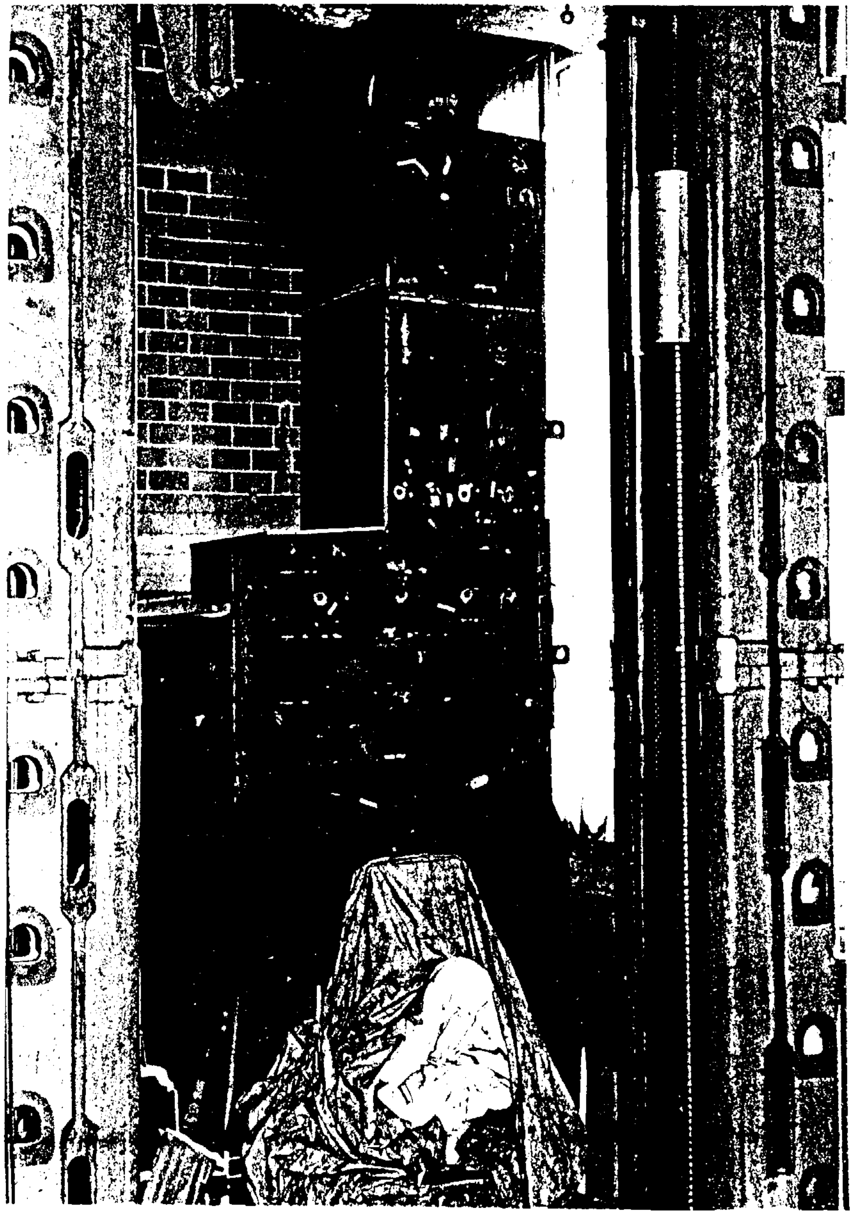


Fig. 9 Specimen 21: Overall view, above deck

Fig. 10 Specimen 21: Overall view, below deck

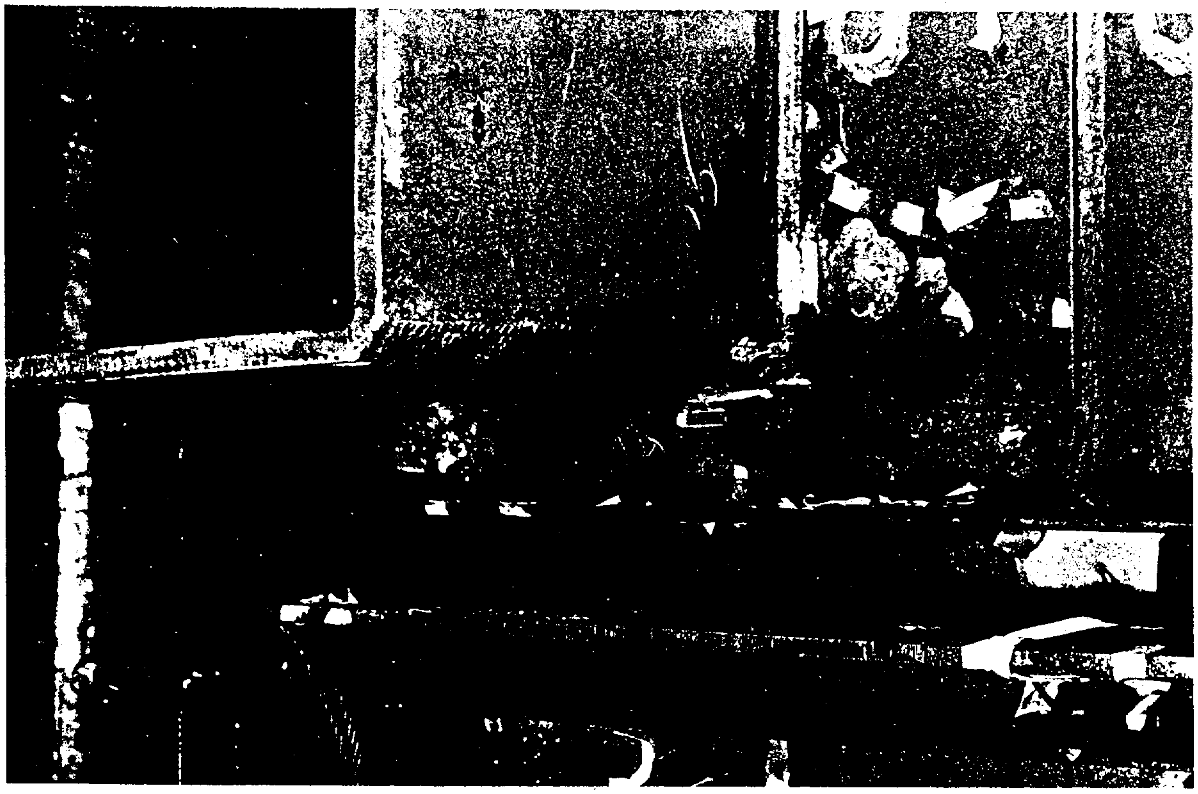


Fig. 11 Specimen 21: Fractures at corner viewed from above

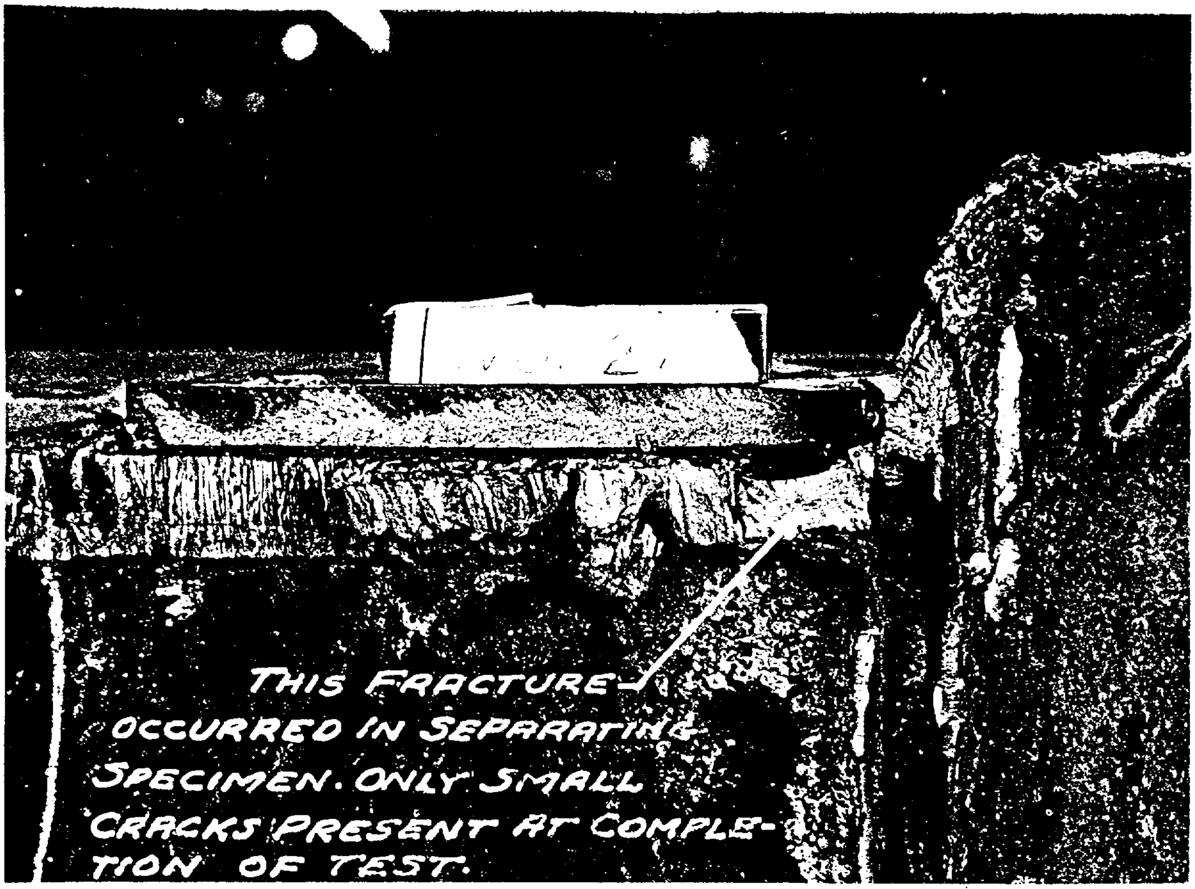


Fig. 12 Specimen 21: Fracture pattern in doubler, looking fwd.

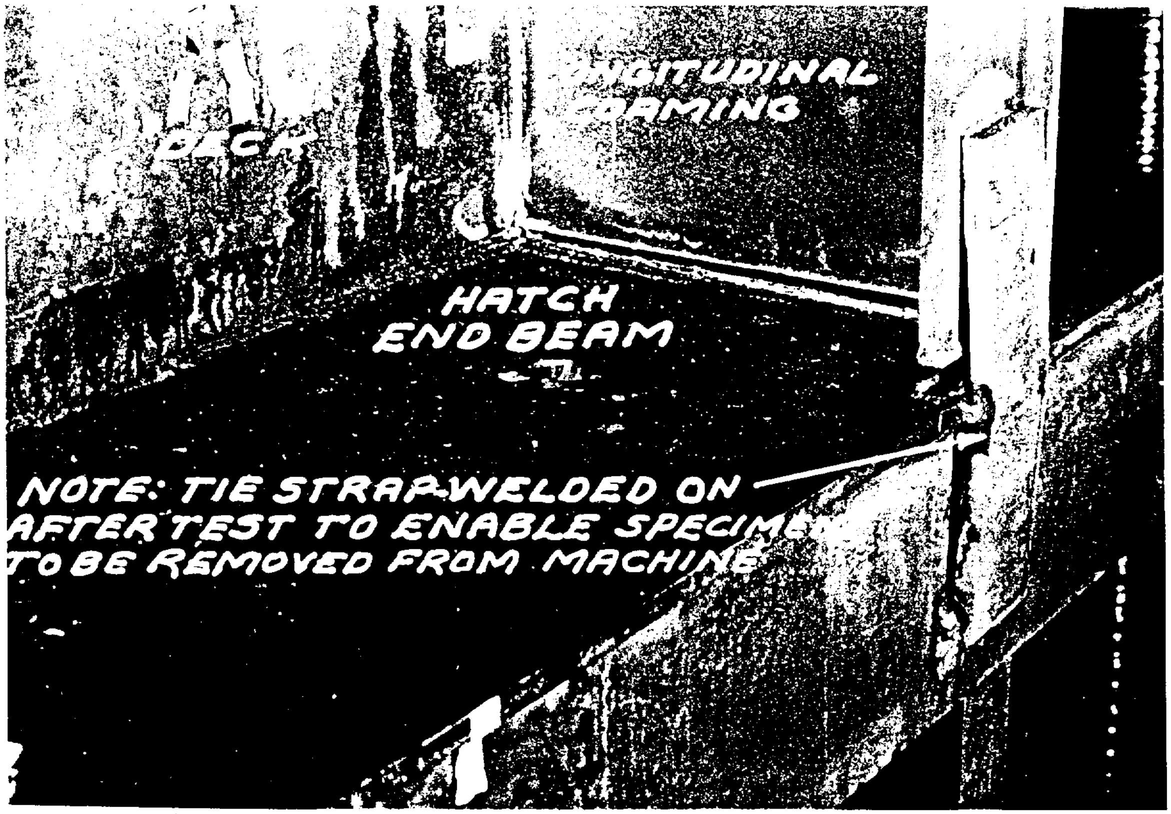


Fig. 13 Specimen 21: Fractures viewed from below deck, outboard, and aft of hatch end beam

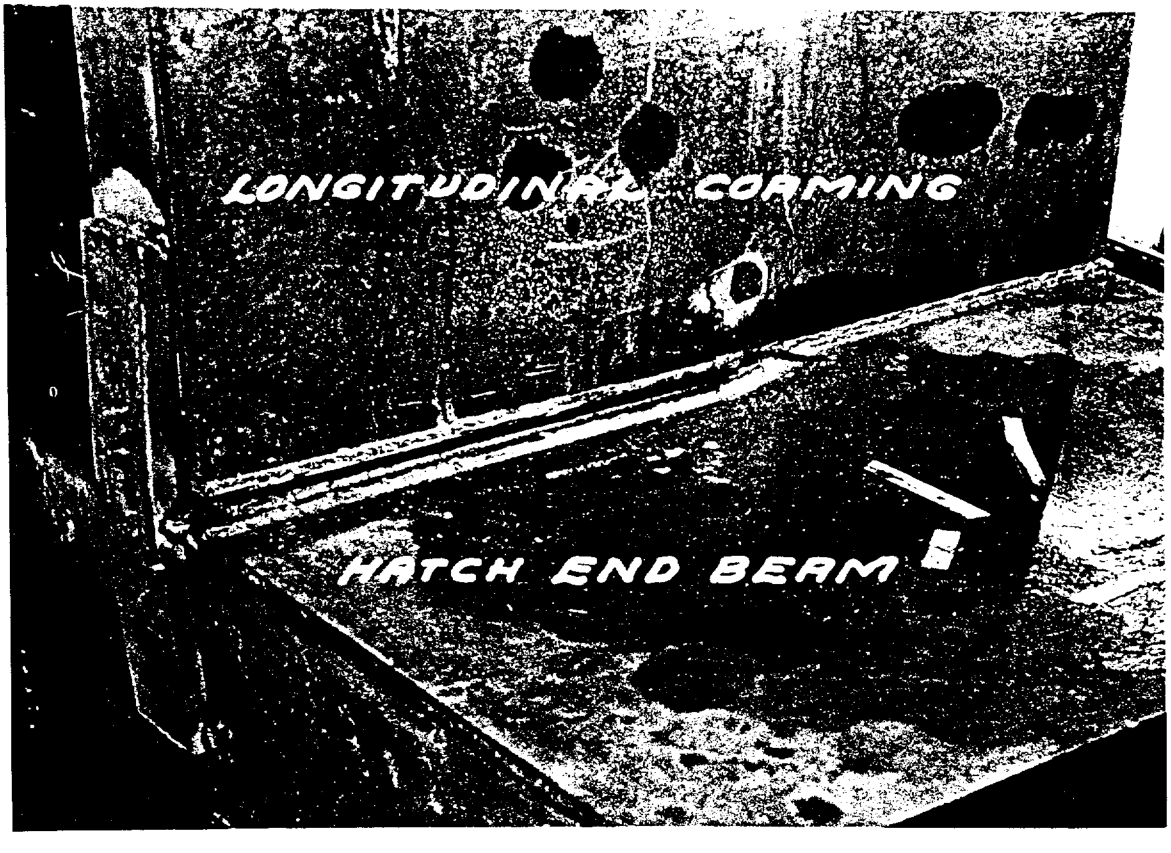


Fig. 14 Specimen 21: Fracture in corner viewed from inside of hatch

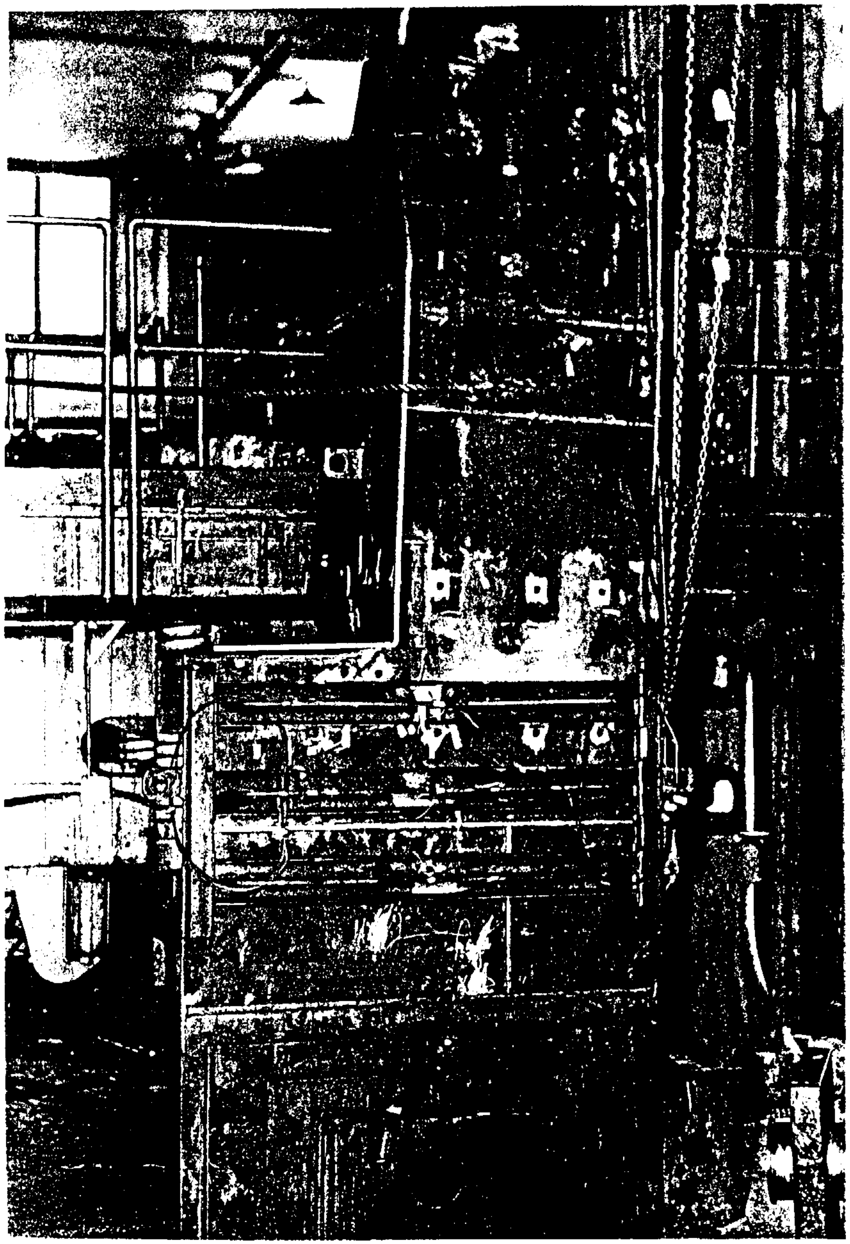


Fig. 15 Specimen 22: Overall view, above deck

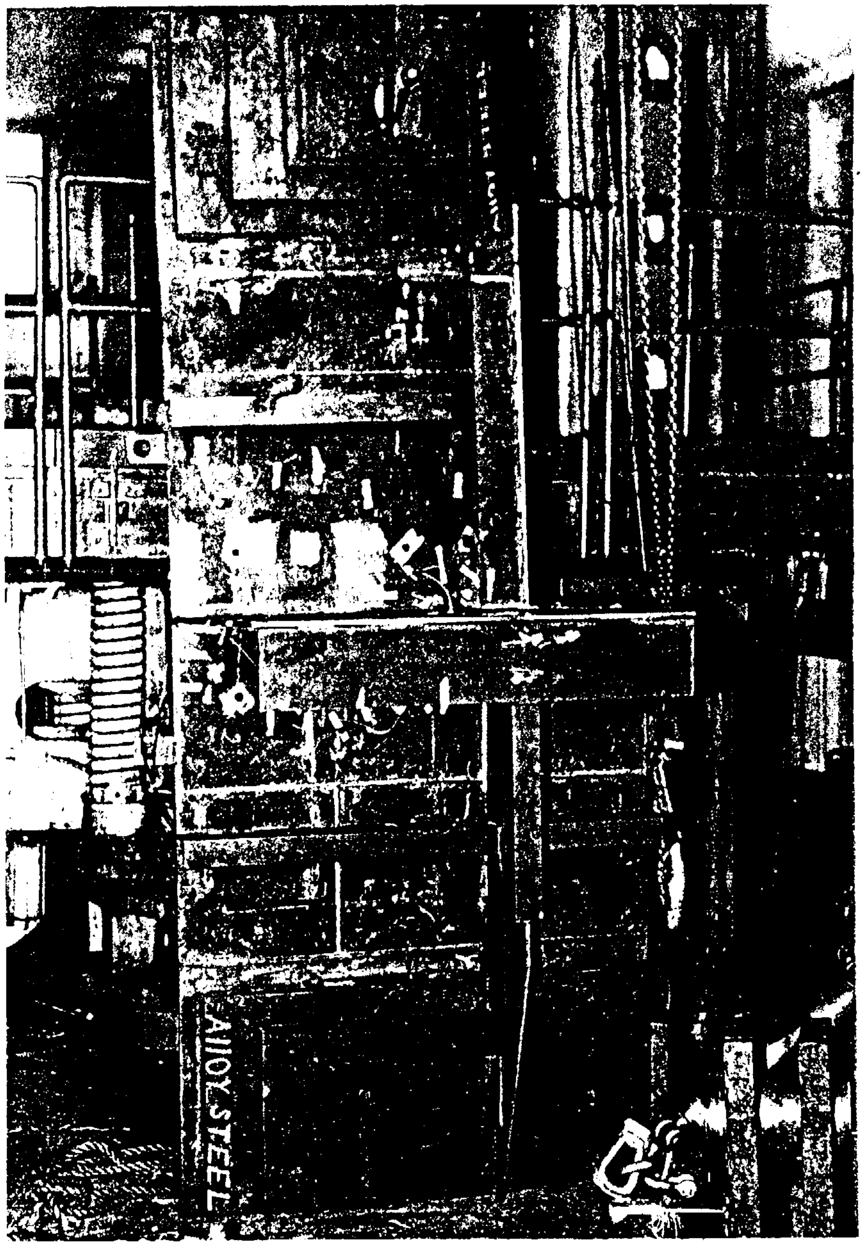


Fig. 16 Specimen 22: Overall view, below deck

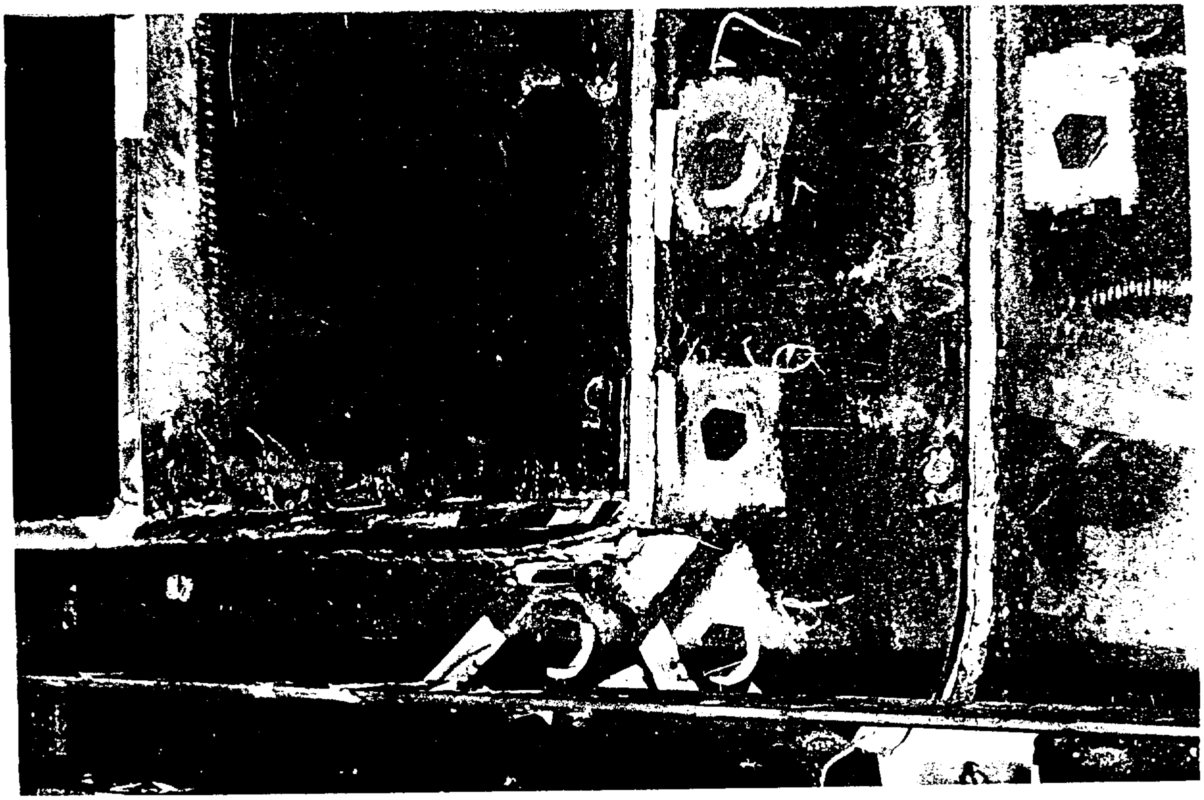


Fig. 17 Specimen 22: Fracture in doubler viewed from above

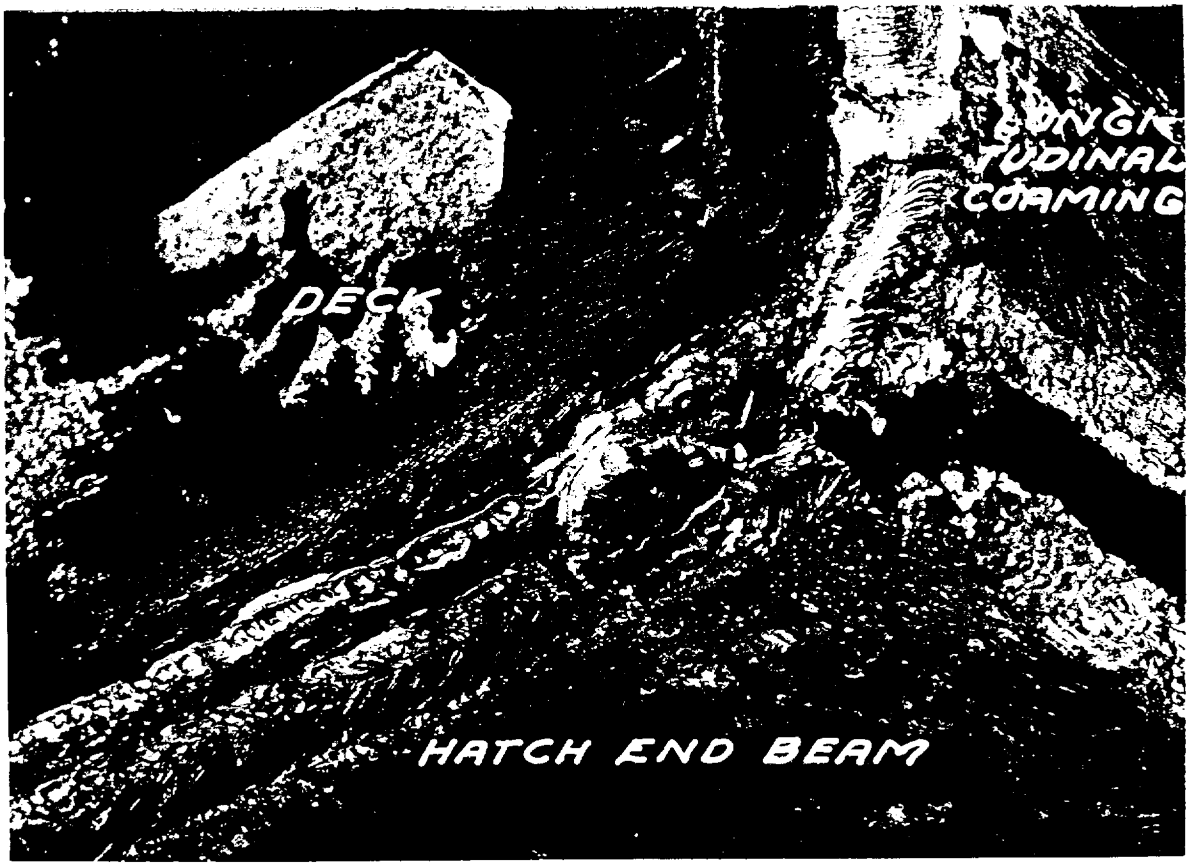


Fig. 18 Specimen 22: Fracture in deck-hatch end beam weld viewed from below deck, outboard, and aft of hatch end beam

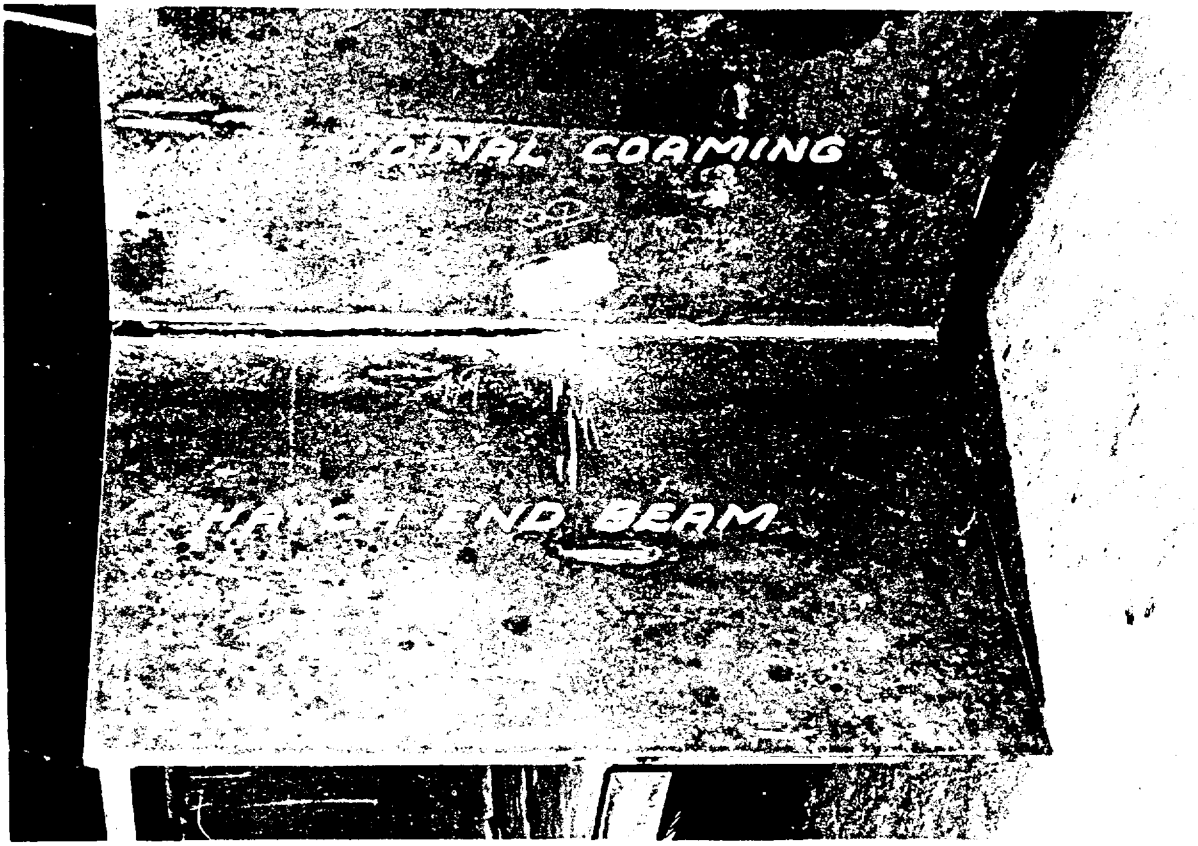


Fig. 19 Specimen 22: Fracture in corner viewed from inside of hatch

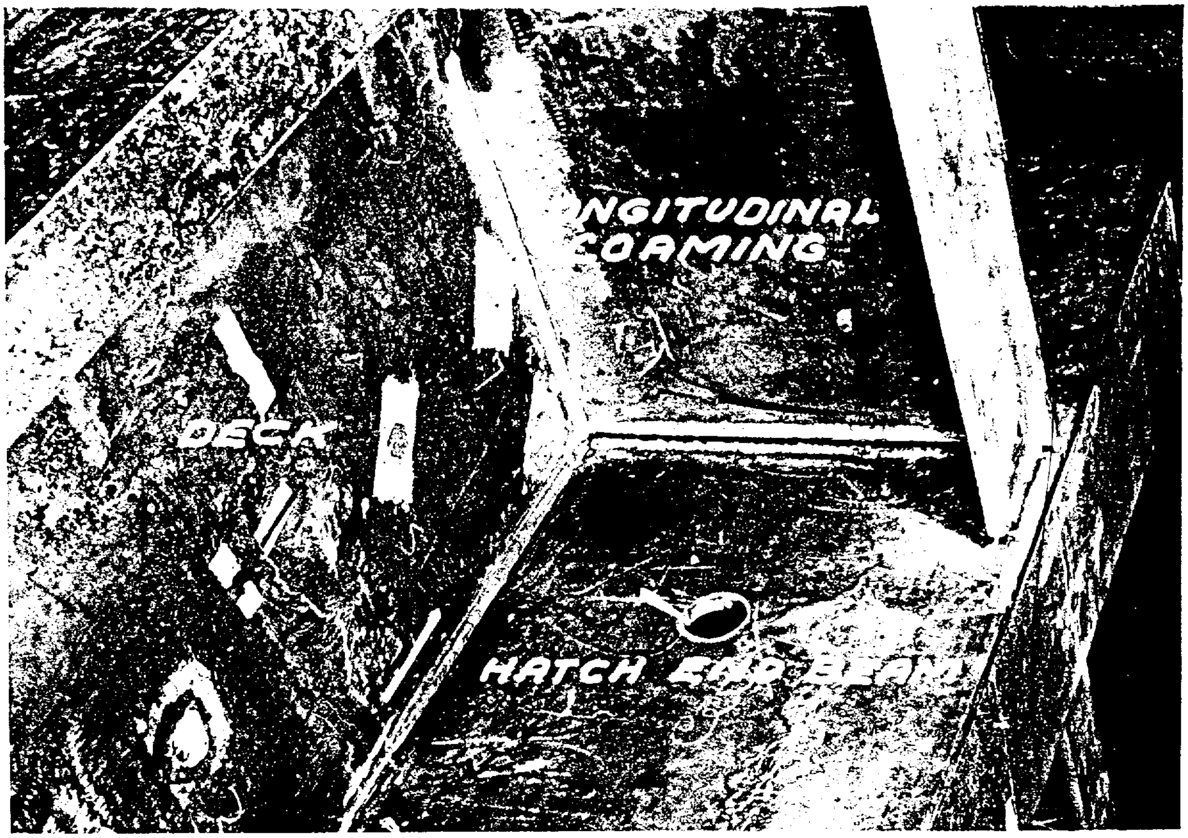


Fig. 20 Specimen 22: Fractures viewed from outboard, below deck, and aft of hatch end beam

Fig. **21** Specimen 22: Fracture pattern in doubler viewed from different angles, looking fwd.

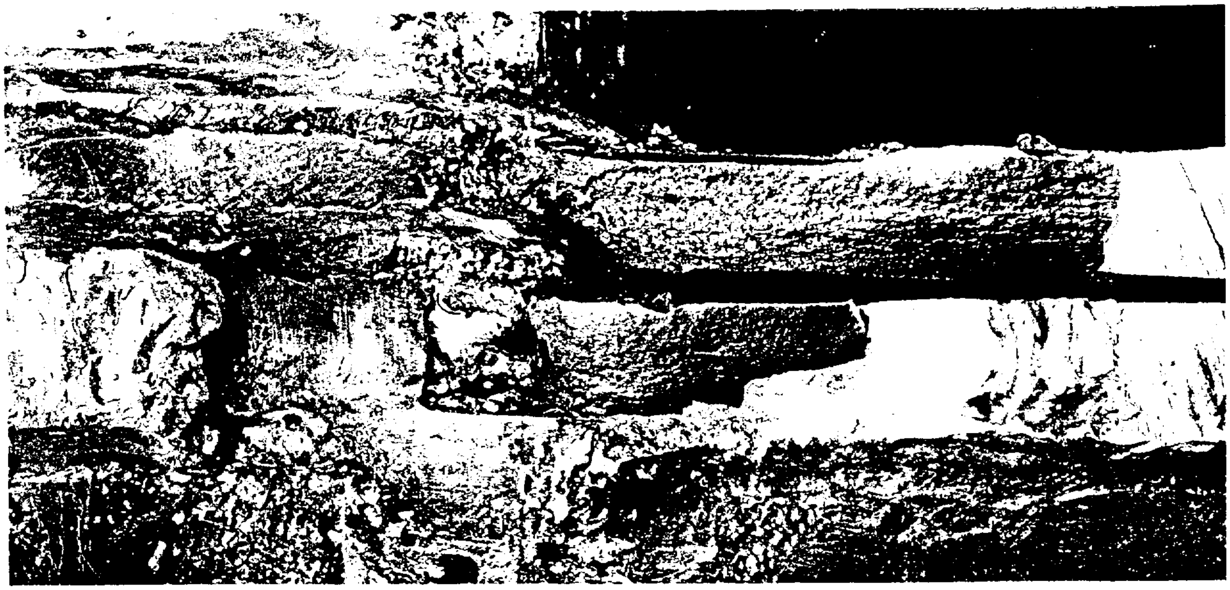


Fig. **22** Specimen 22: Looking aft at fracture patterns in deck and doubler

Fig. 23 Specimen 25: Overall view, above deck

Fig. 24 Specimen 25: Overall view, below deck

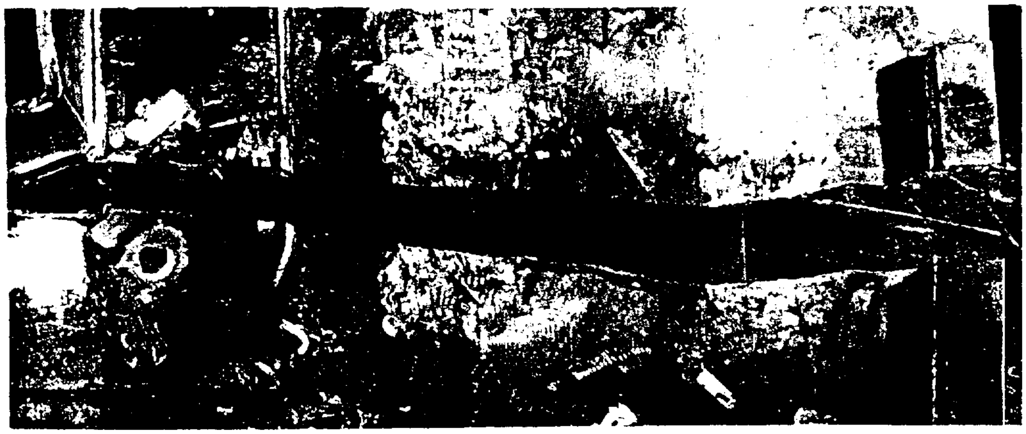


Fig. 25 Specimen 23: Fractures viewed from above deck

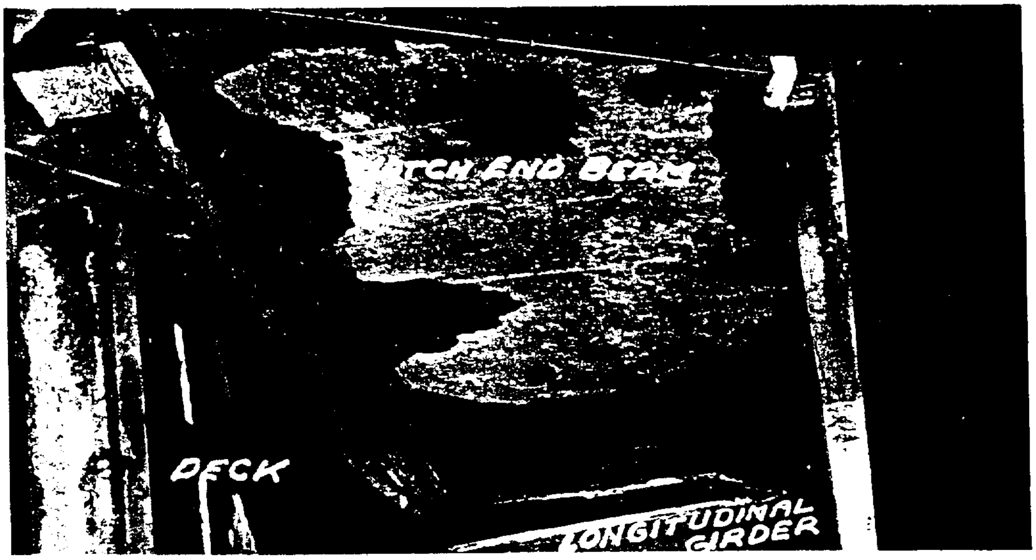


Fig. 26 Specimen 23: Fractures viewed from below deck, outboard, and fwd. of hatch end beam.

Fig. 27 Specimen 23: Fracture in longitudinal coaming-hatch end beam weld viewed from below deck, outboard, and aft of hatch end beam.

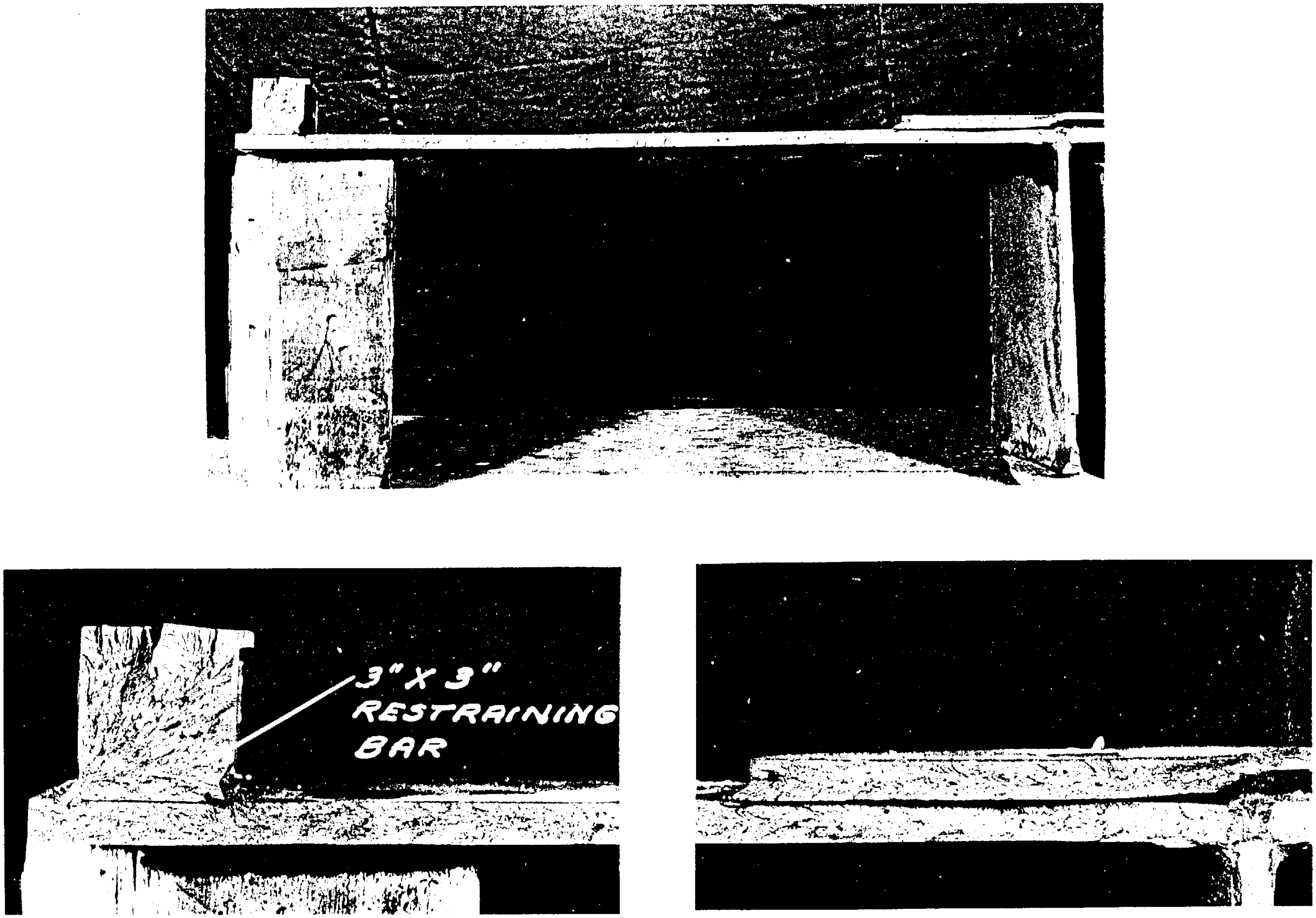


Fig. 28 Specimen 23: Fracture patterns in deck, doubler, and 3" x 3" bar, looking fwd.

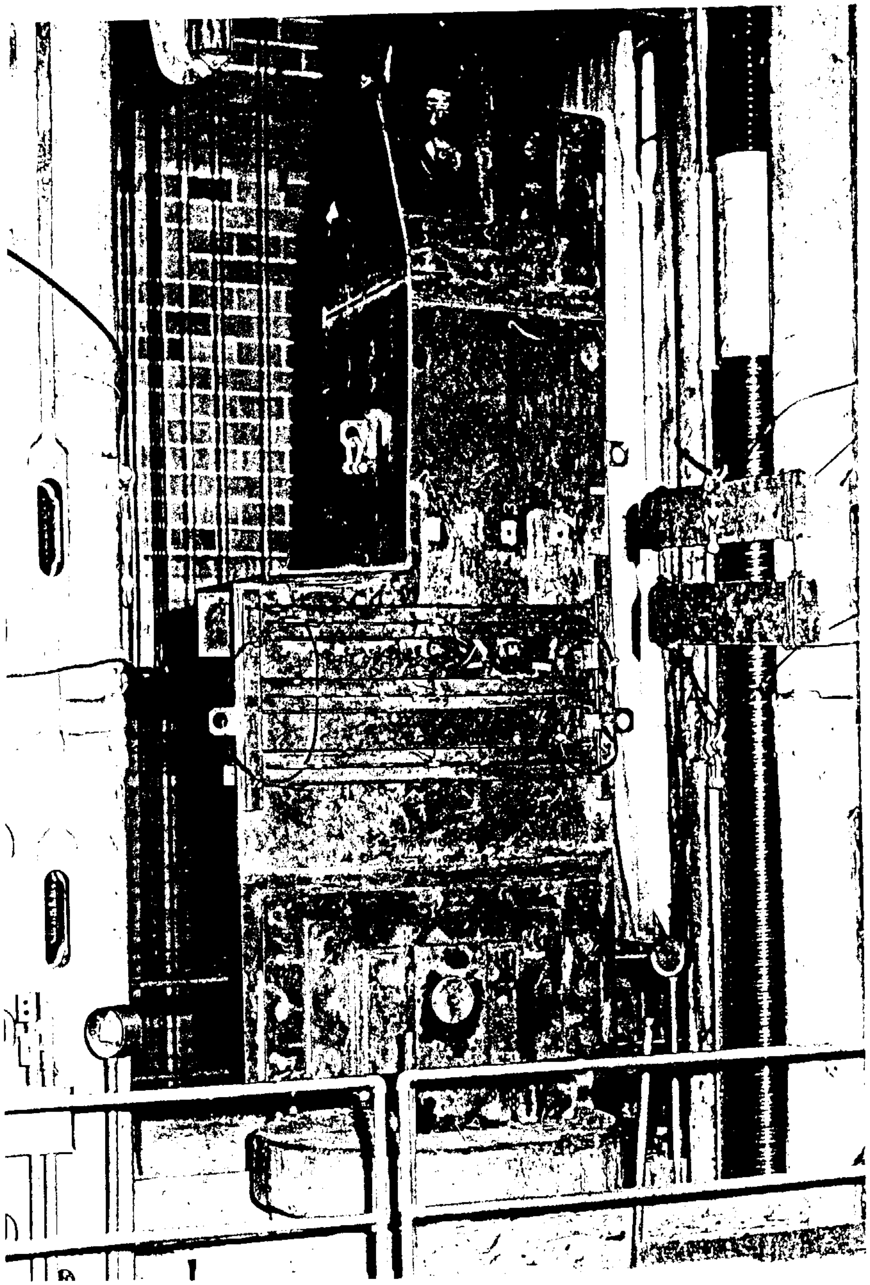


Fig. 29 Specimen 24: Overall view, above deck

Fig. 30 Specimen 24: Overall view, below deck

Fig. 31 Specimen 24: Fractures viewed from above deck.

Fig. 32 Specimen 24: Looking aft at fracture patterns in deck and doubler

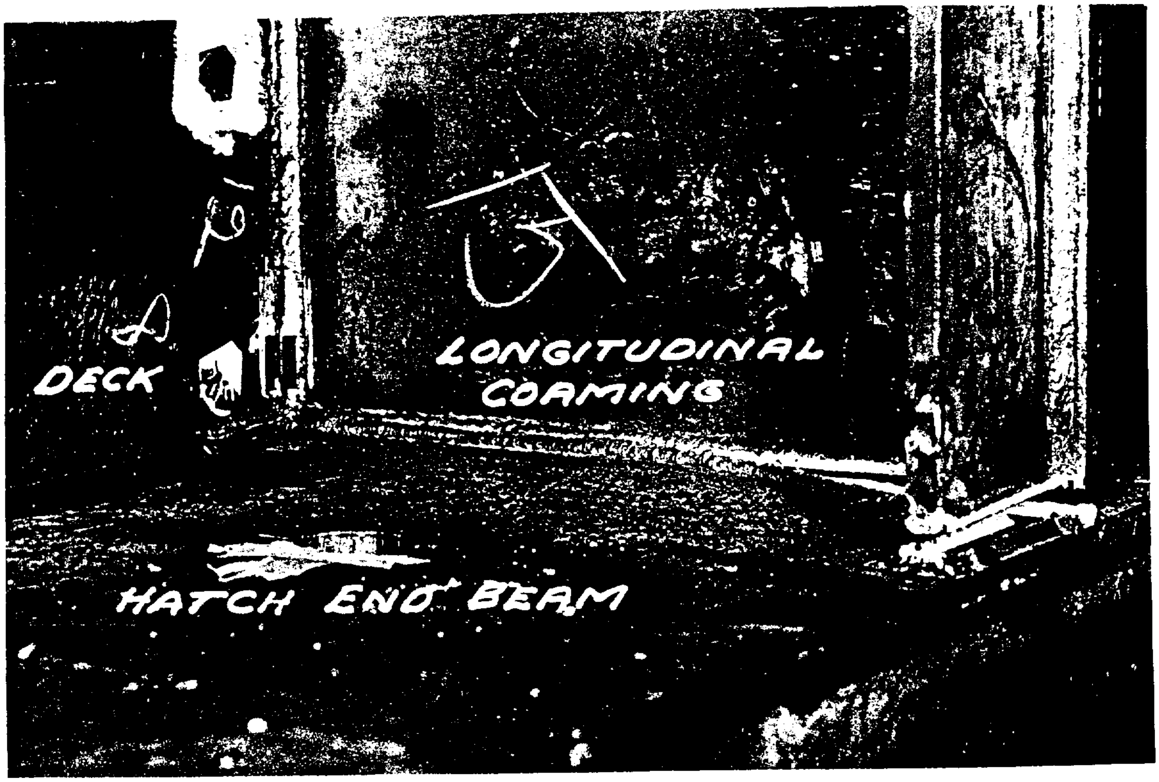


Fig. 33 Specimen 24: Fracture in longitudinal coaming-hatch end beam weld viewed from below deck, outboard, and aft of hatch end beam.

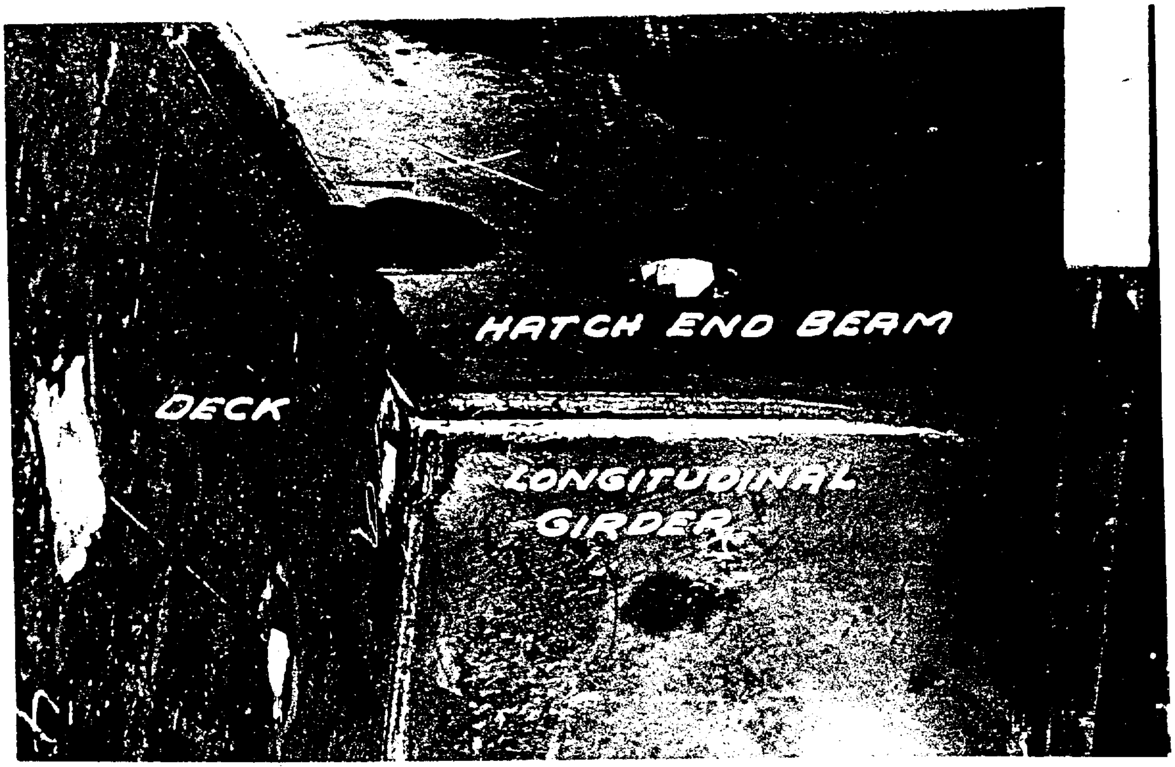


Fig. 34 Specimen 24: Fractures viewed from below deck, outboard, and fwd. of hatch end beam

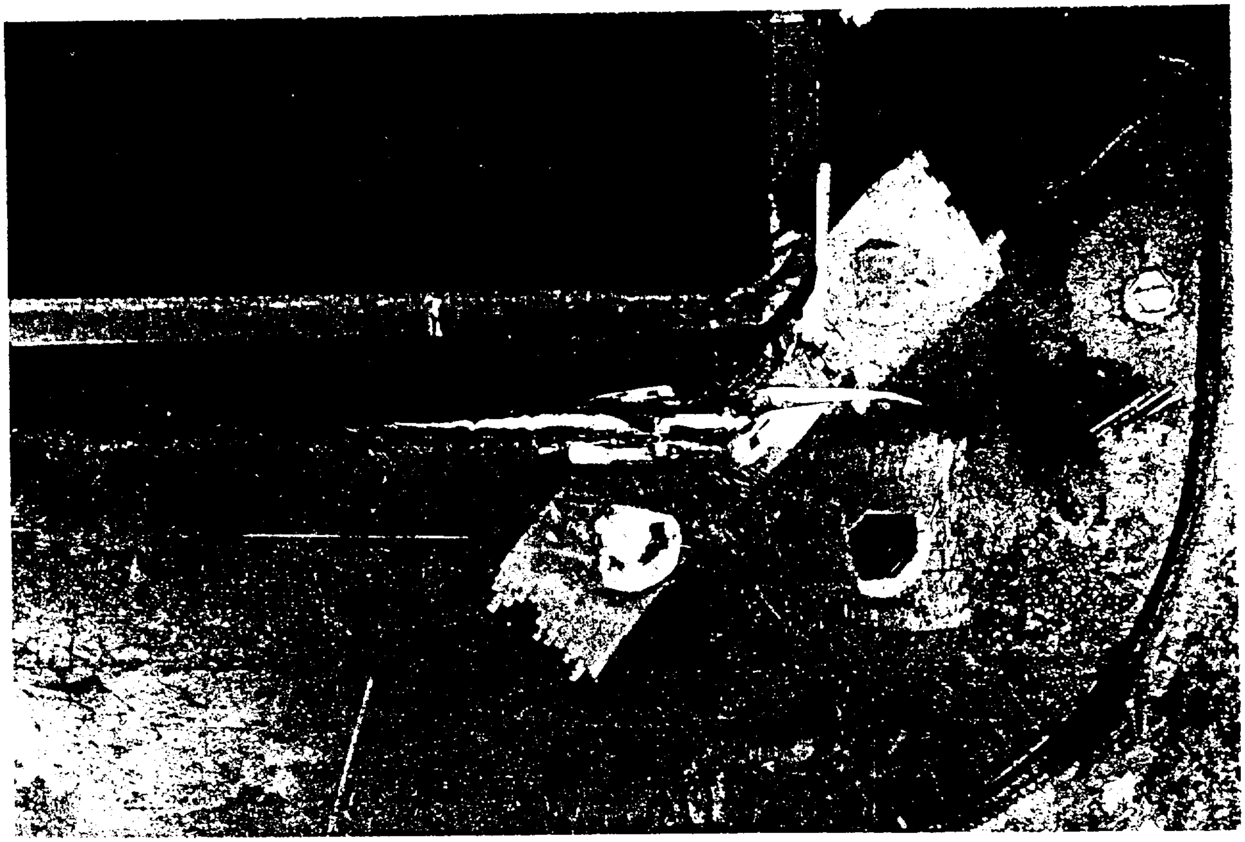


Fig. 35 Specimen 25: Fracture in doubler viewed from above

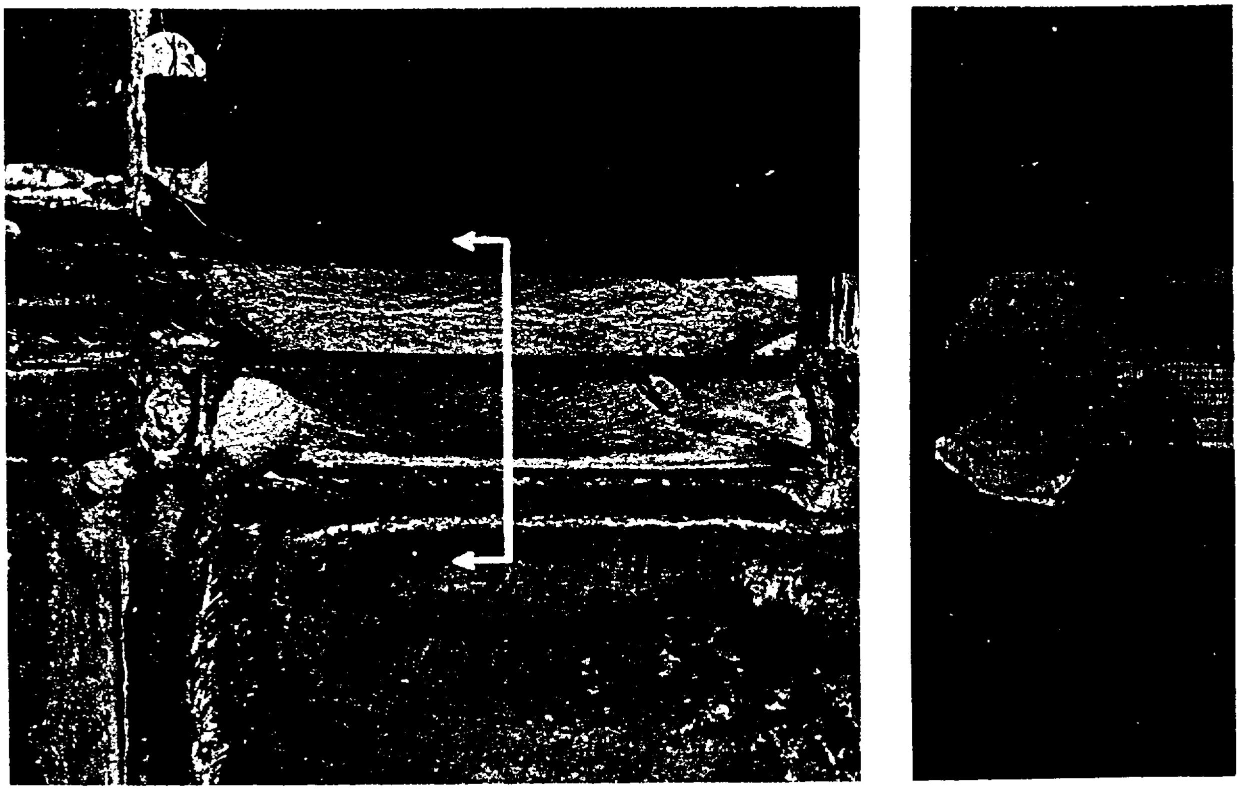


Fig. 36 Specimen 25: Deck and doubler fracture patterns, looking aft; and section, looking inboard

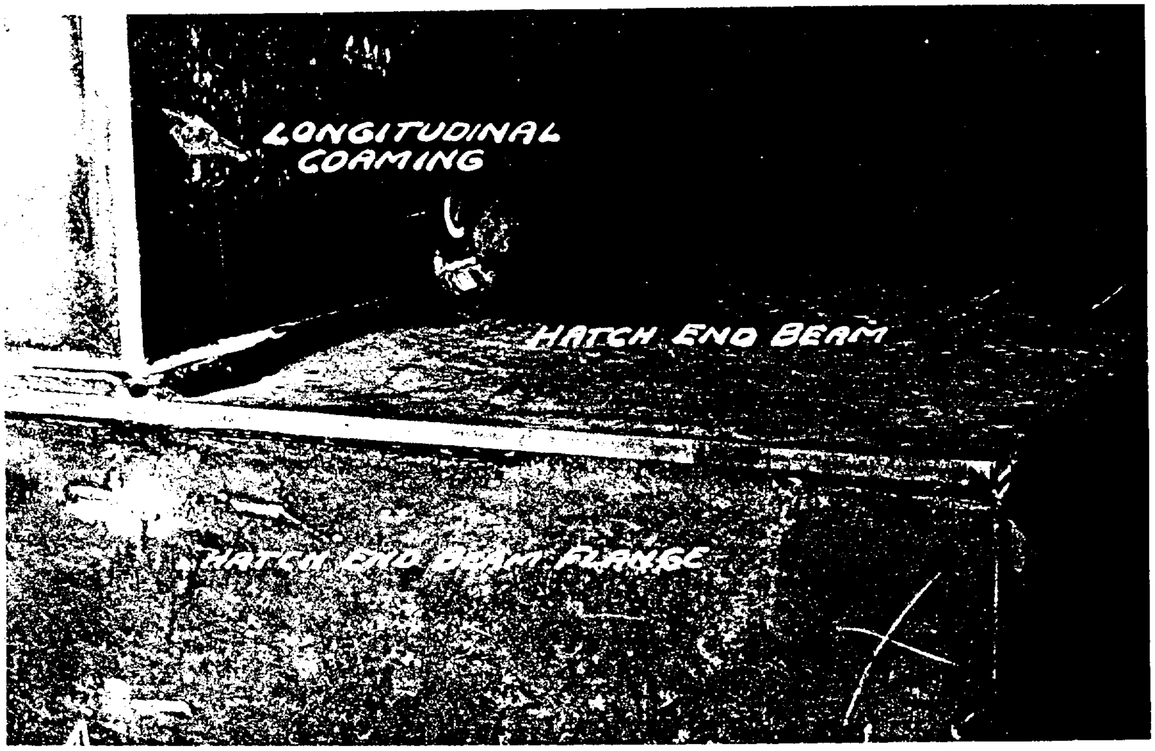


Fig. 37 Specimen 25: Fracture in corner viewed from inside of hatch

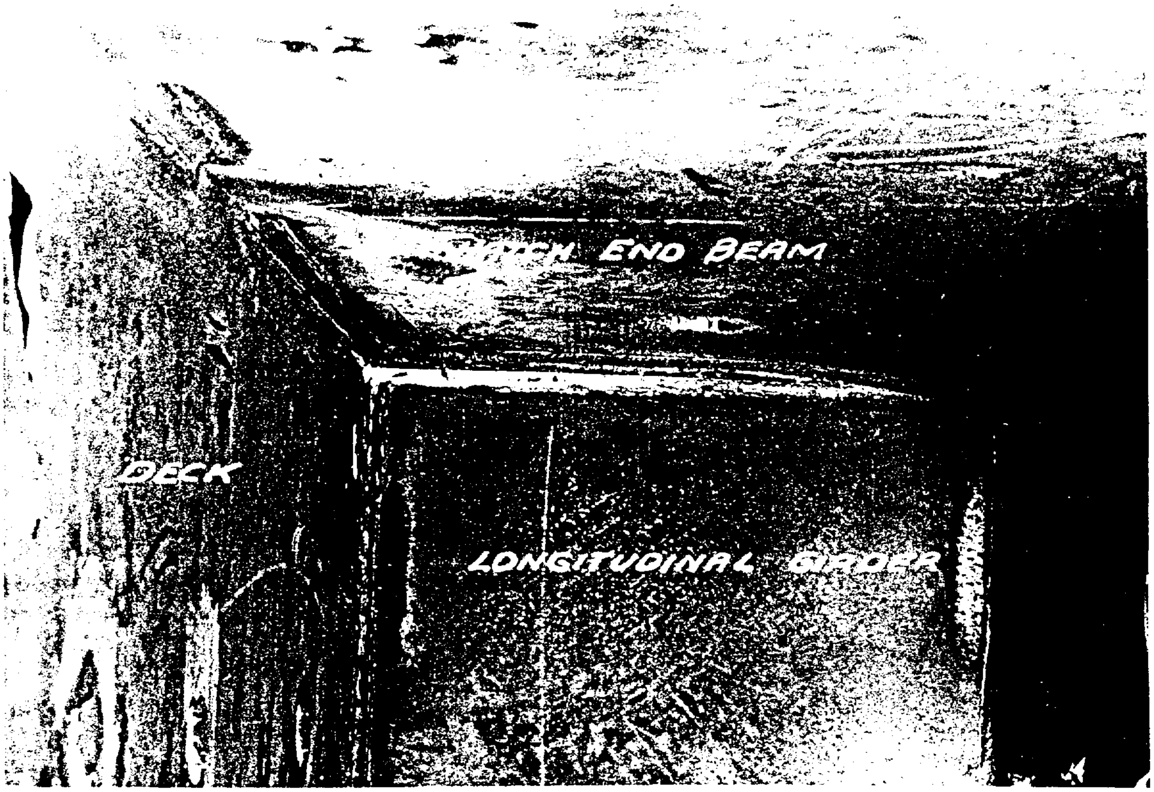


Fig. 38 Specimen 25: Fractures viewed from below deck, outboard, and fwd. of hatch end beam

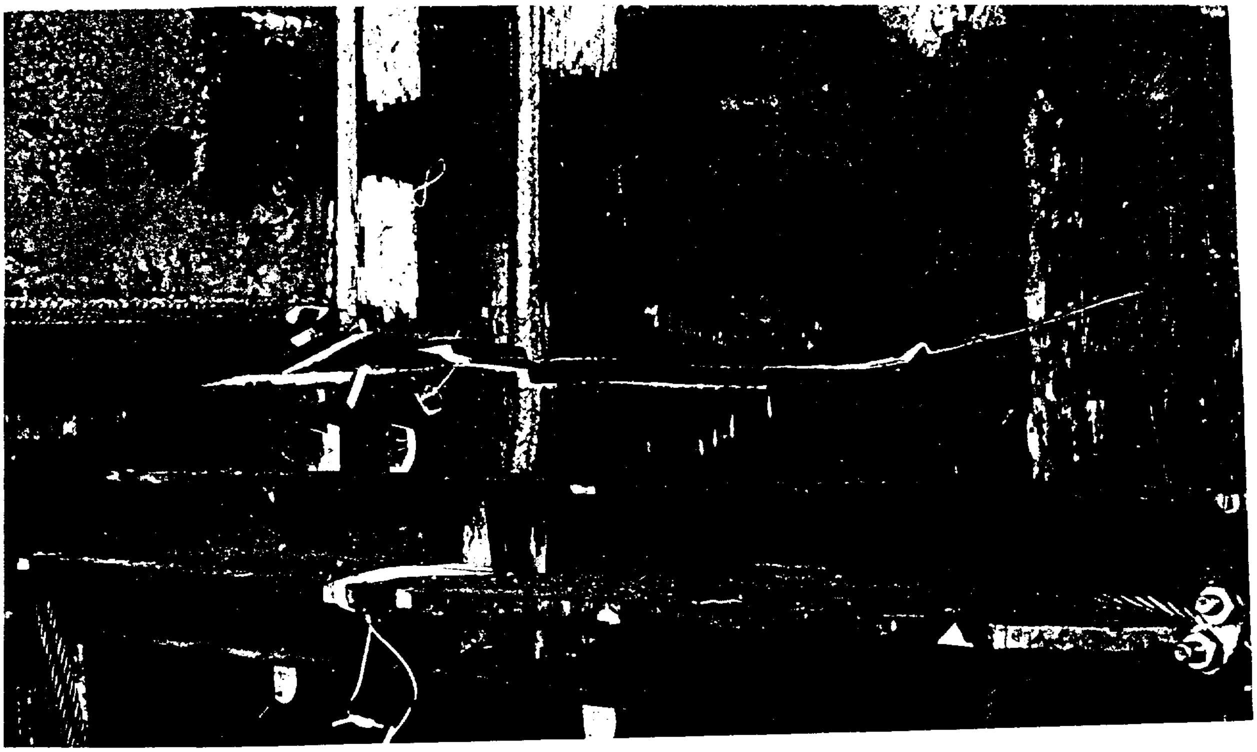


Fig. 39 - Specimen 26: Fractures in deck and doubler, viewed from above

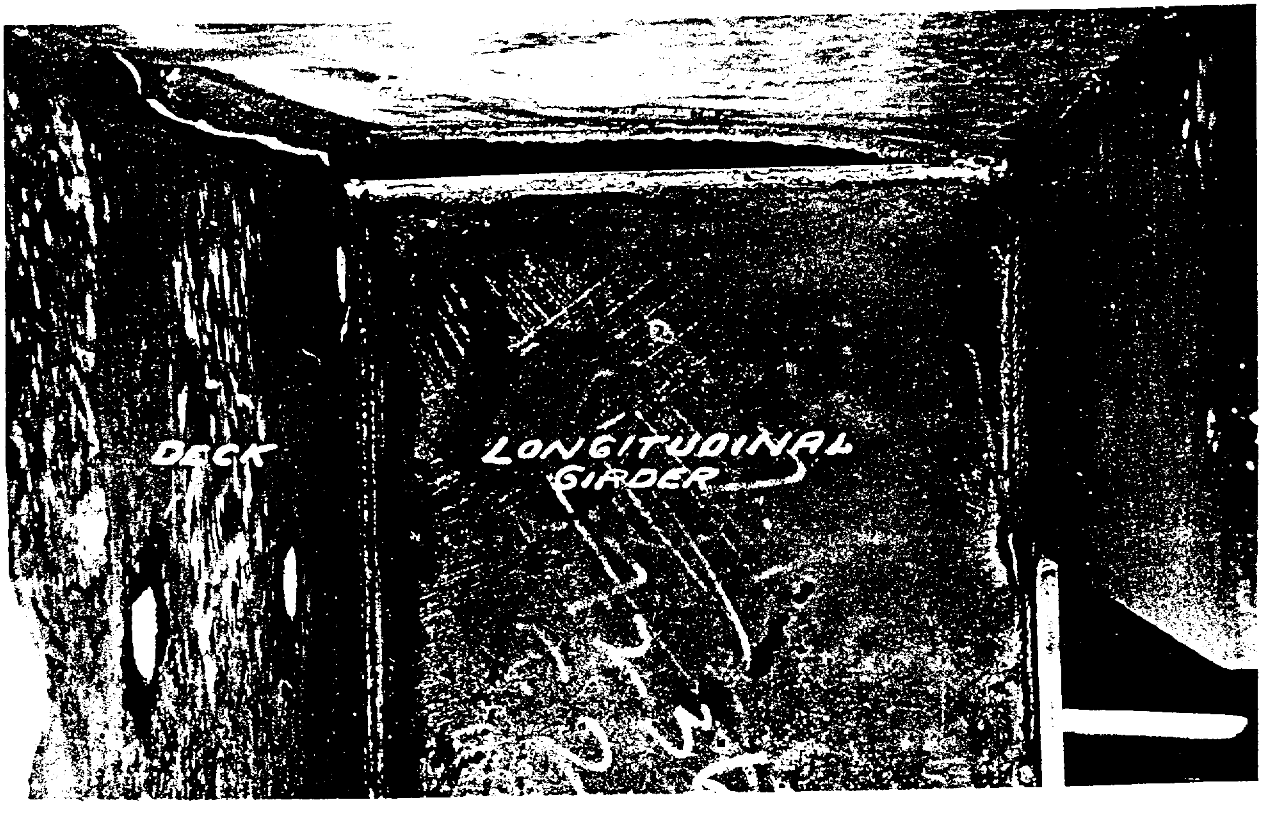
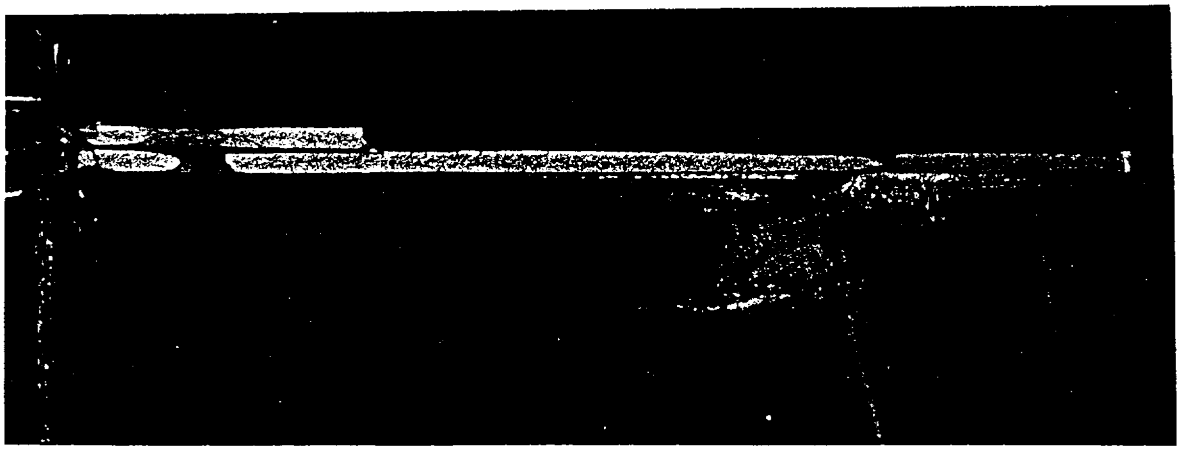
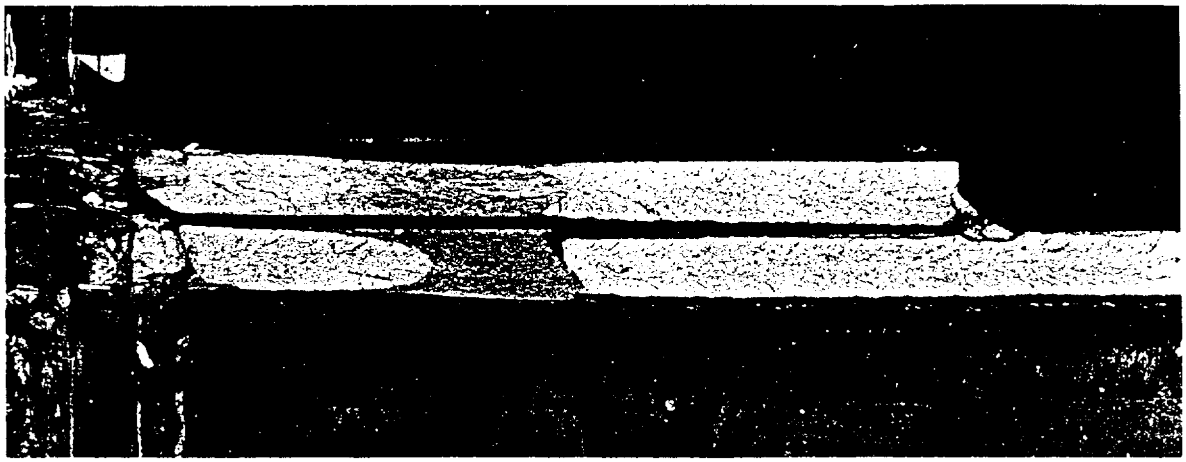


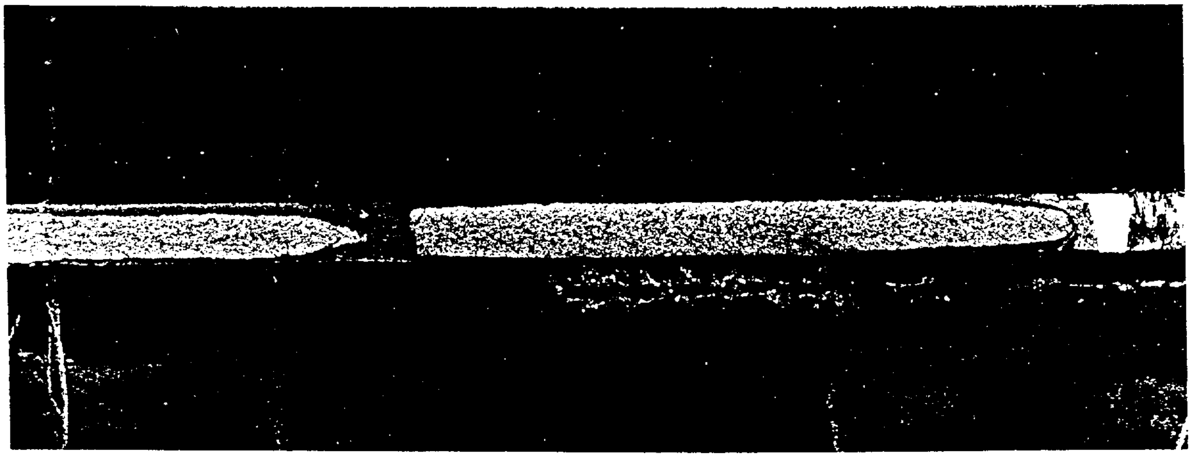
Fig. 40 - Specimen 26: Fracture viewed from below deck, outboard, and fwd. of hatch end beam



Overall view of fractures

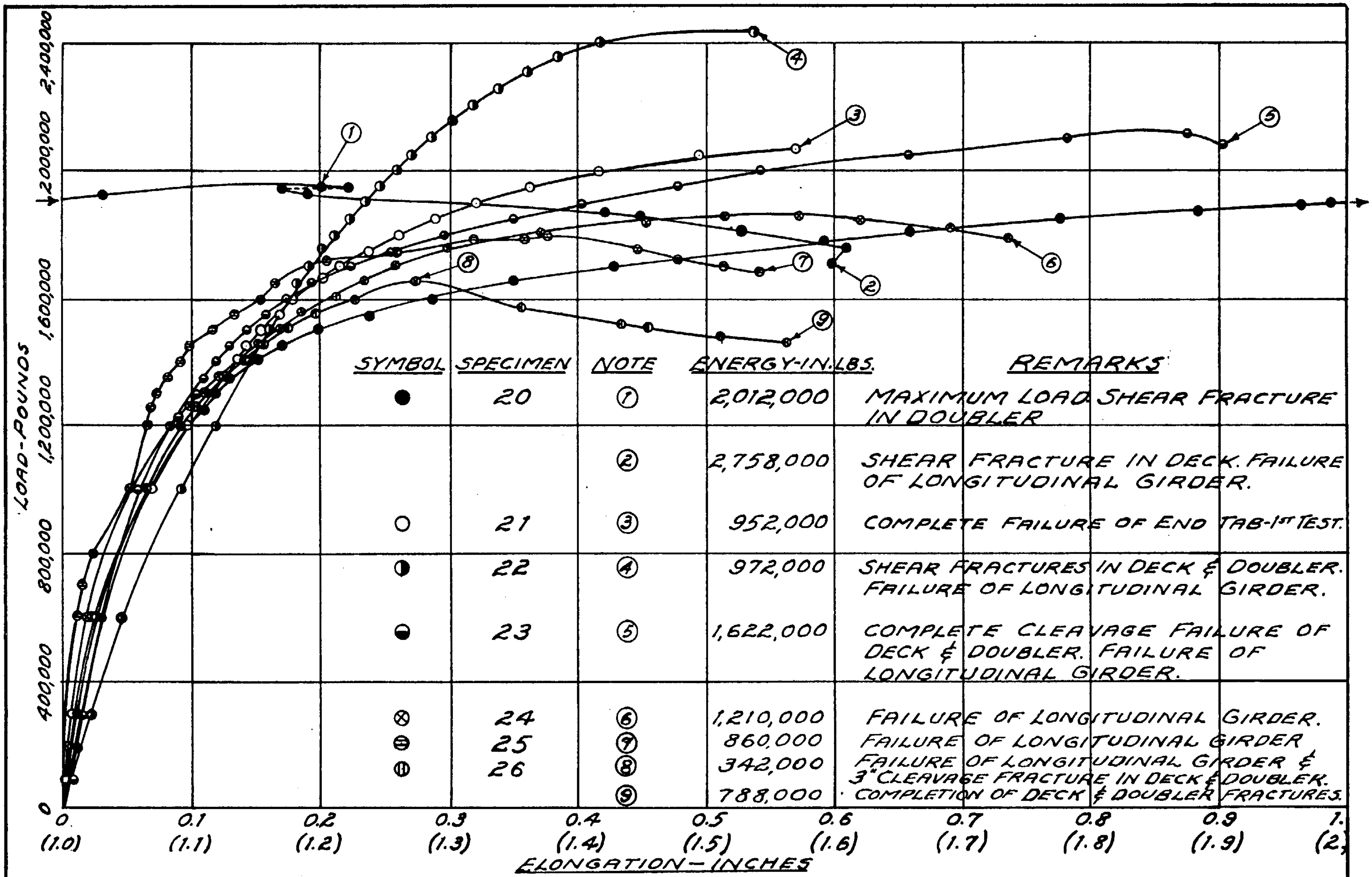


Closeup at corner



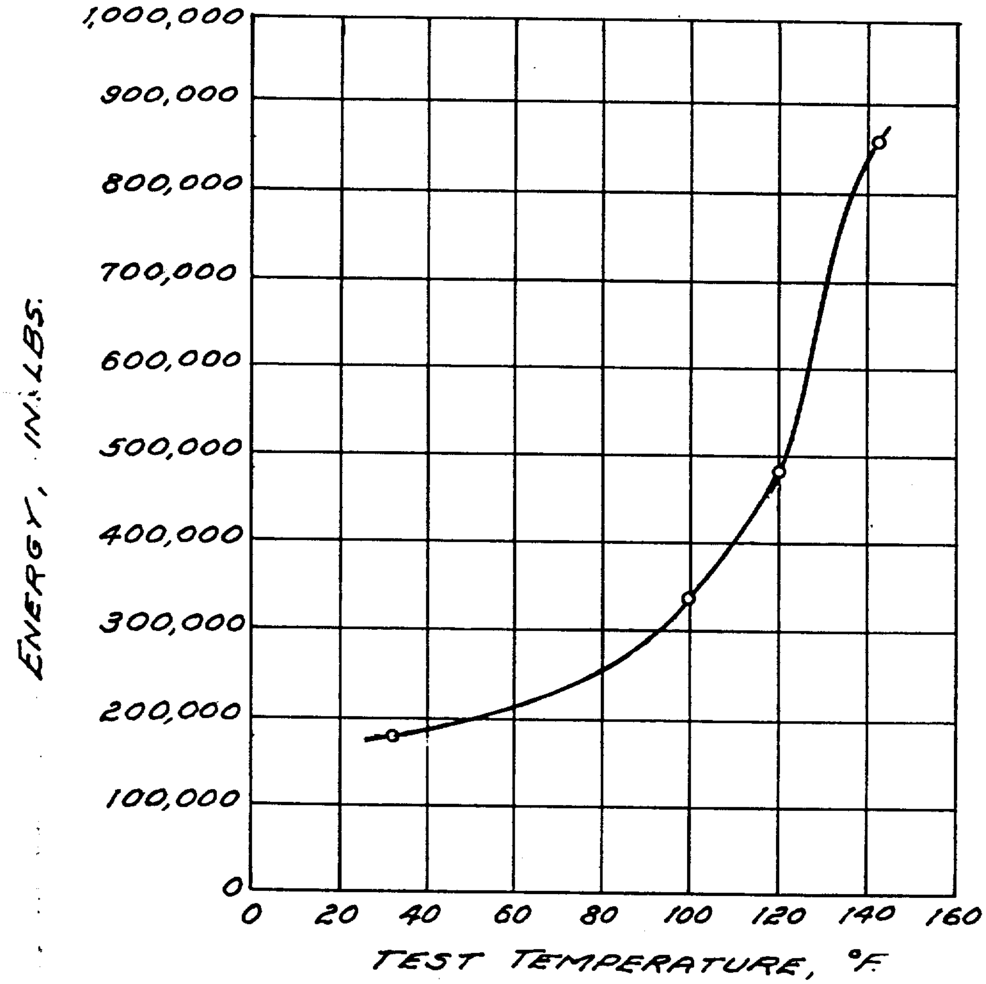
Closeup at end of fracture

Fig. 41 - Specimen 26: Fracture patterns in deck and doubler, looking aft



SYMBOL	SPECIMEN	NOTE	ENERGY-IN-LBS.	REMARKS
●	20	①	2,012,000	MAXIMUM LOAD. SHEAR FRACTURE IN DOUBLER
		②	2,758,000	SHEAR FRACTURE IN DECK. FAILURE OF LONGITUDINAL GIRDER.
○	21	③	952,000	COMPLETE FAILURE OF END TAB-1ST TEST.
◑	22	④	972,000	SHEAR FRACTURES IN DECK & DOUBLER. FAILURE OF LONGITUDINAL GIRDER.
◒	23	⑤	1,622,000	COMPLETE CLEAVAGE FAILURE OF DECK & DOUBLER. FAILURE OF LONGITUDINAL GIRDER.
⊗	24	⑥	1,210,000	FAILURE OF LONGITUDINAL GIRDER.
⊖	25	⑦	860,000	FAILURE OF LONGITUDINAL GIRDER
⦶	26	⑧	342,000	FAILURE OF LONGITUDINAL GIRDER & 3" CLEAVAGE FRACTURE IN DECK & DOUBLER.
		⑨	788,000	COMPLETION OF DECK & DOUBLER FRACTURES.

FIG. 42 LOAD-ELONGATION CURVES (PIN TO PIN MEASUREMENTS)
HATCH CORNER SPECIMENS



ENERGY TEMPERATURE CURVE
HATCH CORNER SPECIMENS
C STEEL

FIG. 43